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Preliminary Application of HSPF (Hydrologic Simulation Program--FORTRAN) to the Iowa River Basin to Model Water Quality and the Effects of Agricultural Best Management Practices

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PRELIMINARY APPLICATION OF HSPF TO THE IOWA RIVER BASIN TO MODEL WATER QUALITY AND THE EFFECTS OF AGRICULTURAL BEST MANAGEMENT PRACTICES

by

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FOREWORD

As environmental controls become more costly to implement and the penalties of judgment errors become more severe, environmental quality management requires more efficient analytical tools based on greater knowledge of the environmental phenomena to be managed. As part of this Laboratory's research on the occurrence, movement, transformation, impact, and control of environmental contaminants, the Technology Development and Applications Branch develops management or engineering tools to help pollution control officials achieve water quality goals.

The Hydrologic Simulation Program--FORTRAN (HSPF), developed through Athens Laboratory research, is a comprehensive technique for modeling water quality constituents in runoff from various land uses. To test the model's capabilities in evaluating the effects of agricultural best management practices (BMPs) on water quality, HSPF was applied to two watersheds in Iowa. The test demonstrated that HSPF is a flexible and realistic technique for BMP assessment in small watersheds and large river basins. Coupled with risk assessment procedures, the model can provide data for use in evaluating impacts of pollutants on selected aquatic organisms.

William T. Donaldson
Acting Director
Environmental Research Laboratory
Athens, Georgia

ABSTRACT

Mathematical models of agricultural runoff processes are being used to analyze and predict the quantity and quality of runoff from agricultural lands. The ultimate goal is to use these models to develop a Best Management Practice (BMP) Plan that will maintain agricultural productivity while minimizing adverse water quality impacts. However, runoff models by themselves are not sufficient to predict water quality effects of BMPs since instream transport and transformations are not usually represented. Although agricultural runoff models can be used to evaluate BMP effects on runoff and pollutant loadings from small, field-size areas, they must be linked with receiving water quality models to assess the quality in receiving waters resulting from BMPs applied to the watershed.

This report describes a basin-scale model application which combines the detailed simulation of agricultural runoff and soil processes, which calculates surface and subsurface pollutant transport to receiving waters, with subsequent simulation of instream transport and transformations. The result is a comprehensive simulation of river basin water quality. Comparison of water quality resulting from conventional agronomic practices and BMPs provides the basis for determining the net effects and associated benefits of BMP implementation. Using simulated concentrations of pesticides and other toxic pollutants in conjunction with lethality-duration information, the frequency of acute and chronic toxic conditions can be determined to assess the aquatic impact of proposed practices.

This report was submitted by Anderson-Nichols & Co. in partial fulfillment of Contract No. 68-03-2895 under the sponsorship of the U.S. Environmental Protection Agency. The work was completed as of November 1981.

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Among the authors, Mr. John Imhoff was the Task Leader for this study. He was heavily involved in development of the simulation plan including the definition of the land segmentation and channel reach schemes. In addition, Mr. Imhoff assisted with simulation of instream hydraulics, and sediment and nutrient processes . Mr. Brian Bicknell was the key staff engineer on the project. He assisted in the development of agricultural practices and chemical applications, developed HSPF input sequences, and executed the simulation runs. Mr. Anthony Donigian was the Principal Investigator and Project Manager with overall responsibility for the technical direction of the project. He also directed the simulation of land surface hydrology and chemical processes, and developed and analyzed the Best Management Practice scenarios for pesticide and nutrient runoff control.

Many other individuals at Anderson-Nichols were active on this work. Mr. Jack Kittle was our key technical source on all HSPF operational questions. Ms. Kathryn Lahanas provided the necessary text editing for this report. Ms. Mary Maffei provided clerical support and report typing throughout the project, and Ms. Virginia Rombach prepared the report charts and figures, and assisted in preparation of the hydraulics portion of the input sequences. The dedication and efforts of these individuals contributed greatly to the success of the project.

SECTION 1

INTRODUCTION

Mathematical models of agricultural runoff processes are being used to analyze and predict the quantity and quality of runoff from agricultural lands. The ultimate goal is to use these models to develop a Best Management Practice (BMP) plan that will maintain agricultural productivity while minimizing adverse water quality impacts. However, runoff models by themselves are not sufficient to predict water quality effects of BMPs since instream transport and transformations are not usually represented. Although agricultural runoff models can be used to evaluate BMP effects on runoff and pollutant loadings from small, field-size areas, they must be linked with receiving water quality models to assess the quality in receiving waters resulting from BMPs applied to a watershed or basin. Moreover, the runoff and receiving water quality models must be compatibly designed, so that the runoff and agricultural pollutant loadings (e.g., sediment, pesticides, nutrients) can be accepted, transported, and transformed by the associated aquatic processes in the receiving water model. Thus, predicting water quality in agricultural watersheds requires integrated, comprehensive modeling systems so that conventional practices and changes affected by BMPs can be represented by the runoff models with the resulting water quality conditions determined by the receiving models.

It was recognized early in our work that a major problem in modeling water quality in large river basins would be the representation of sediment and pollutant delivery from generation on field-size areas to a stream, where the aquatic impact is exerted. Although sediment delivery (with associated pollutants) is entirely a land surface process, delivery and movement of soluble pollutants occurs by both surface and subsurface pathways; usually the subsurface path is dominant. The ability of integrated runoff/receiving water models to represent the delivery process is uncertain. Also, the manner in which BMPs affect the distribution between surface and subsurface pollutant transport and delivery has a significant impact on the resulting water quality. Thus, both of these problem areas are important to BMP analyses.

This report describes a demonstration application of comprehensive hydrology and water quality modeling on a large river basin to evaluate the effects of agricultural nonpoint pollution and proposed BMPs. The investigation of the Iowa River Basin described in this report is an extension of a modeling study on the 52 square kilometer Four Mile Creek watershed in Central Iowa (Donigian et al., 1983b). That study combined detailed simulation of agricultural runoff and soil processes to calculate surface and subsurface pollutant transport to receiving

waters for comprehensive simulation of watershed water quality. Subsequent comparison of water quality conditions under conventional agronomic practices and BMPs provided the basis for estimating the net effects and associated benefits of BMP implementation. Using simulated concentrations of pesticides in conjunction with lethality-duration information, the frequency of acute and chronic toxic conditions was used to assess the aquatic impact of proposed practices.

1.1 Iowa Field Evaluation Program Overview

The research work and modeling results presented in this report were performed as part of a comprehensive Field Evaluation Program (FEP) (U.S. EPA, 1979), sponsored by EPA and coordinated by the Athens Environmental Research Laboratory. The primary purposes of the FEP were to test and demonstrate (1) the capability of agricultural best management practices to achieve water quality goals, and (2) the applicability of two water quality planning tools - the Hydrologic Simulation Program FORTRAN - HSPF (Johanson et al., 1980) and the Chemical Migration and Risk Assessment (CMRA) methodology (Onishi et al., 1979) to the BMP evaluation and selection process.

These objectives of the FEP were to be accomplished through a series of studies in the Iowa-Cedar river basin in the State of Iowa (Figure 1.1). The primary focus of the FEP was the Four Mile Creek basin near Traer, Iowa, a 52 square kilometer agricultural watershed that was the site of a study of sediment, nutrient, and pesticide fate and transport by EPA and Iowa State University.

Extensive field monitoring and data collection programs at the Four Mile Creek site supported the FEP to provide the necessary data for the BMP analysis and modeling efforts. The FEP included the participation of local farmers in Four Mile Creek and local, state, and federal agencies in order to demonstrate the BMP evaluation, selection, and implementation process.

Although EPA budgetary cutbacks in 1980 curtailed the data collection program and limited the BMP implementation efforts in Four Mile Creek, the modeling effort was continued and completed as a demonstration of current technology.

1.2 Modeling Analyses in the IFEP

Both HSPF and the CMRA methodology have been applied in the Iowa FEP to evaluate and demonstrate their utility for BMP analyses. HSPF is a comprehensive program for modeling runoff, sediment, pesticides, nutrients, and other water quality constituents from urban, agriculture, and other land uses. It allows detailed simulation of stream hydraulics, water quality processes,

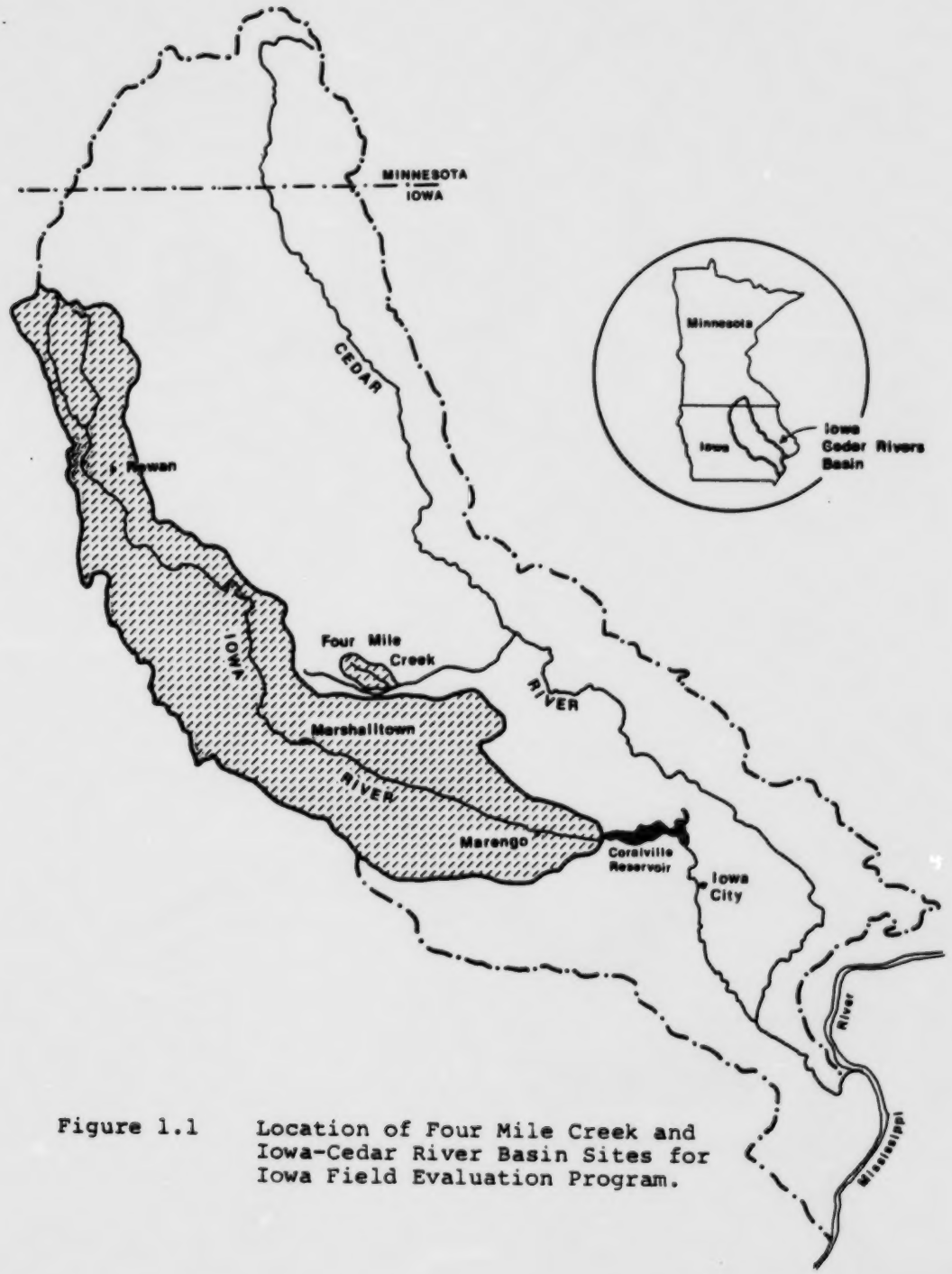

Figure 1.1 Location of Four Mile Creek and Iowa-Cedar River Basin Sites for Iowa Field Evaluation Program.

pesticide and nutrient behavior in soil, lake/reservoir dynamics, and sediment-contaminant transport. It also includes extensive data handling and analysis procedures that support and complement the simulation capabilities.

The CMRA methodology provides procedures for detailed instream simulation of sediment and chemical transport and interactions to develop time series of chemical concentrations in streams. The time series is then characterized by a frequency-duration relationship for use with toxicity data to assess the frequency of acute and chronic toxic conditions for aquatic organisms. The CMRA methodology is comprised of four components: the ARM model is used to simulate pesticide loading to the stream; the EXPLORE model (Baca et al., 1973) simulates stream hydraulics; the SERATRA model (Onishi and Wise, 1979) simulates instream sediment transport, contaminant decay mechanisms, and sediment/contaminant interactions; and the FRANCO model (Olsen and Wise, 1979) performs frequency analyses of the contaminant concentration time series in order to assess the relative occurrence of acute and chronic toxic conditions.

Since both HSPF and CMRA include the ARM model functions and identical statistical capabilities, there is some duplication in the models. As part of the Four Mile Creek study, HSPF was modified to include the basic SERATRA and FRANCO model capabilities in order to provide a single comprehensive system to analyze water quality and toxic conditions for assessing the aquatic impact of candidate BMPs.

Complete descriptions of HSPF capabilities and algorithms are provided in the HSPF User's Manual (Johanson et al., 1981), and summary discussions have been presented by Barnwell and Johanson (1981) and Grimsrud et al., (1980). The Four Mile Creek report (Donigian et al., 1983b) documents the overall methodology followed in this study and summarizes specific HSPF capabilities relevant to modeling agricultural chemical fate and transport.

1.3 Objectives of this Study

As noted above, the modeling analyses of the Iowa FEP included the application and evaluation of HSPF (with the CMRA capabilities) to both the data-intensive Four Mile Creek watershed and the large Iowa River Basin (7240 square kilometers) above Coralville Reservoir. The Four Mile Creek Study provided the opportunity for (1) integration of the CMRA methodology into HSPF, (2) detailed calibration with observed runoff, sediment, and chemical data, and (3) development of methodologies to analyze impacts of conventional agronomic practices and proposed BMPs. The objective of this study was to extrapolate the methodology developed on Four Mile Creek to the Iowa River Basin to demonstrate its applicability and functionality on a large river basin.

This study is a 'preliminary' demonstration application of HSPF because data and resource limitations precluded extensive calibration on the Iowa River. In many cases model parameter values from Four Mile Creek were applied directly to the study area without adjustment, whereas other parameters were modified based on available information and engineering judgement. In essence, this study allowed us to explore the problems associated with modeling hydrology, sediment, and chemical fate and transport in a large river basin with varying meteorologic conditions, soils, and cropping practices.

This report documents the procedures and assumptions we used in applying HSPF to the Iowa River Basin. The simulation results presented are indicative of the type of information produced by HSPF. However, the specific results and comparisons with observed data should not be used as a final determination of the accuracy or reliability of HSPF because of the preliminary nature of this work. Moreover, the model results should not be used as a basis for planning decisions on agricultural nonpoint pollution and BMPs in the Iowa River Basin without additional calibration efforts and re-evaluation of the underlying assumptions presented in this report. This investigation was directed to the assessment of operational problems of modeling chemical fate and transport at the river basin scale. Recommendations are included to provide guidance for further improvements in HSPF and to direct future modeling efforts on the Iowa River Basin.

SECTION 2

CHARACTERIZATION OF THE IOWA RIVER BASIN FOR APPLICATION OF HSPF

The initial step in applying HSPF to a river basin is the development of a simulation plan or strategy, based on characterization of the area with regard to meteorologic conditions (and spatial variability), soils characteristics, topography, land use, pollutant sources, available historic data, etc. Meteorologic data must be identified which are representative of the various portions of the basin to be modeled. A basin segmentation scheme must be developed which defines areas of homogeneous hydrologic response based on soils characteristics and land use, as well as weather conditions. A representative channel system including both hydraulic and geometric characteristics is needed. Streamflow and water quality data which can be used to calibrate the model must be examined, and a modeling strategy which makes full use of available data must be devised. The relative importance of various pollutant sources must be ascertained. For those pollutant sources which are deemed significant to model results a general characterization of pollutant behavior (accumulation, removal, influence by, and response to, land use activities) must be defined. The purpose of this section is to outline the characterization process which was used to develop the simulation plan and basin segmentation strategy for the Iowa River Basin.

2.1 Meteorologic, Hydrologic, and Water Quality Data

This portion of the report focuses on the selection of meteorologic, streamflow, and water quality data required to perform the Iowa River Basin simulation. First, the general availability of data within the basin is discussed. Subsequently the time-series data requirements for the HSPF model are outlined, and the necessity of segmenting the watershed (i.e., using different weather station records to represent different areas) is assessed in general terms. The criteria used to select the best station record(s) for each required data type are presented, and the quality of the selected records is assessed. Finally, the data selected for use in the Iowa River Basin simulation are summarized in tabular form.

General Availability of Data. There are 18 NOAA weather stations in or near the 7,236 square kilometer Iowa River Basin above Marengo. The stations and the type of data available at each station are presented in Table 2.1, and the location of each station in relation to the watershed boundary is shown in Figure 2.1. Additional meteorologic data were available from the Iowa State University and Four Mile Creek Weather Station near Traer. Precipitation, maximum and minimum air temperatures, humidity, pan evaporation, solar and net radiation have been recorded at

TABLE 2.1 STATION INDEX FOR IOWA RIVER BASIN METEOROLOGIC DATA

Station	Meteorologic Data *
Ames 8 WSW	P,T,E,O
Cedar Rapids FAA AP	P,T,O
Des Moines WSFO AP	P,T,O
Forest City	P,T
Grinnel 3 SW	P,T
Iowa City	P,T,E
Iowa City Ralston 2	P
Iowa City Raltson 5	P
Iowa City Ralston 6	P
Iowa Falls	P,T
Marshalltown	P,T
Mason City FAA AP	P,T,O,
North English	P
Ottumwa FAA AP	P,T,O,
Sheffield	P
Traer	P
Waterloo WSO AP	P,T,O
Webster City	P,T

P=hourly precipitation
E=daily potential evapotranspiration
T=daily max-min temperature
O=other daily meteorologic data (dewpoint temp., wind speed).

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Figure 2.1 Meteorologic and U.S.G.S. Gaging Stations in and near the Iowa River Basin.

this station. However, the station was closed during winter months and has experienced numerous equipment failures; consequently, records are incomplete.

The United States Geologic Survey currently maintains nine stream gages in the Iowa River Basin. The locations of these gages are listed in Table 2.2 along with drainage area and period of record information. The stream gages can be located on Figure 2.1. In addition to these nine gages, records for two discontinued gages are available (W. Branch of Iowa River at Klemme and Iowa River at Belle Plaine).

Daily suspended sediment loadings data were available for the Iowa River at Marengo, Iowa. Sampling and analysis have been performd at this site by the U.S. Army Corps of Engineers on a continuous basis since 1968.

Water quality data for the Iowa River are limited. While the U.S. EPA data bank STORET contains data for various water quality constituents at 29 locations along the river, sampling at most locations was infrequent and did not provide information on temporal variations of chemical concentrations which is needed for model calibration. The two sampling locations with the best nutrient data were located at the Highway 220 bridge north of South Amana and near the waterworks plant in Marshalltown. Pesticide data were limited to a handfull of grab samples at Coralville Reservoir and Lake Rathbun in south central Iowa.

Simulation Data Needs. Hydrologic and water quality calibration of HSPF requires the following time-series data:

1. precipitation
2. potential evapotranspiration
3. air temperature
4. wind speed
5. solar radiation
6. dewpoint temperature
7. streamflow and water quality data

In order to perform a reasonable hydrologic calibration, the watershed must be divided into land segments such that each segment produces a homogeneous hydrologic response. Factors which must be considered in determination of segmentation include land use/cropping practices, soils characteristics, and meteorologic patterns. To determine whether meteorologic variation should be accounted for in selecting segments, two factors must be considered. First, the degree of spatial variability exhibited by the data type must be examined. For instance, data suggest that in the Iowa River Basin mean annual air temperature has a much more significant variability across the watershed than does wind speed.

TABLE 2.2 USGS STREAM GAGES IN THE IOWA RIVER BASIN

Station No.	Location	Drainage Area (km2)	Period of Record
4490	East Branch of the Iowa River at Klemme	344	1948-76
4495	Iowa River near Rowan	1111	1940-76
4515	Iowa River at Marshalltown	4051	1932-present
4517	Timber Creek near Marshalltown	306	1949-present
4519	Richland Creek near Haven	145	1949-present
4520	Salt Creek near Elberon	521	1945-present
4522	Walnut Creek near Hartwick	184	1949-present
4530	Big Bear Creek at Ladora	490	1945-present
4531	Iowa River at Marengo	7236	1956-present

Second, the impact of the data type on simulation results must be considered. Some data types such as precipitation and evapotranspiration are direct determinants of water availability while other data types only affect streamflow timing by altering rate of spring snowmelt. (For the hydrologic calibration air temperature, wind speed, solar radiation, and dewpoint temperature are all used exclusively in the snowmelt calculations.) Consequently, if significant variability does exist over the watershed for a critical data type such as precipitation or evapotranspiration, the use of multiple weather station records is warranted. Simulation results can be further improved in those cases where multiple records for the other meteorological data types are readily available.

Selection of Time Series Data. In the following discussion the critera used to select meteorologic, streamflow, and water quality data for the Iowa River Basin simulation are outlined. Each data type is summarized separately since the selection procedure varied depending on availability of data for the 1974-1978 simulation period, spatial variability of the data type within the basin, and impact of the data type on simulation results.

Precipitation - Mean annual precipitation for the basin varies from 762 millimeters in the north to 838 millimeters in the southeast (Figure 2.2). Given the primary importance of precipitation data to the simulated water balance, three records were used. Both long term averages and records for the selected simulation period (1974-1978) suggest that the Traer precipitation is representative of the southeastern third of the basin, which receives 813 to 838 mm of yearly rainfall.

The central section of the basin has a long term average annual precipitation in the range of 787 to 838 mm, and can be well represented by the Iowa Falls record. The Iowa Falls station recorded an average of 757 mm of annual rainfall during the 1974-1978 simulation period, somewhat lower than the long term average. (Lower than average rainfall was recorded at all stations within the basin for the 1974-1978 period.) The Iowa Falls record was generally good. Records were missing for 17 days, and were filled in using data from the Ames station.

The northern section of the basin is characterized by 762 to 787 mm of average rainfall. Inspection of the records for the two best candidate stations, Forest City and Sheffield, showed large periods of missing data for both. Sheffield was selected as the base record and was updated using Forest City data when available (43 days). Remaining gaps (53 days) were filled using Iowa Falls data.

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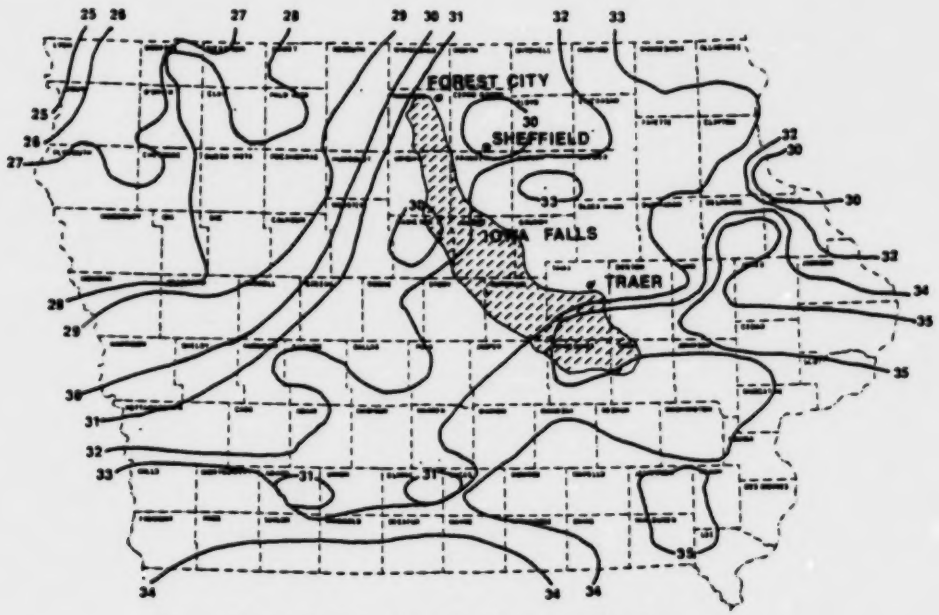
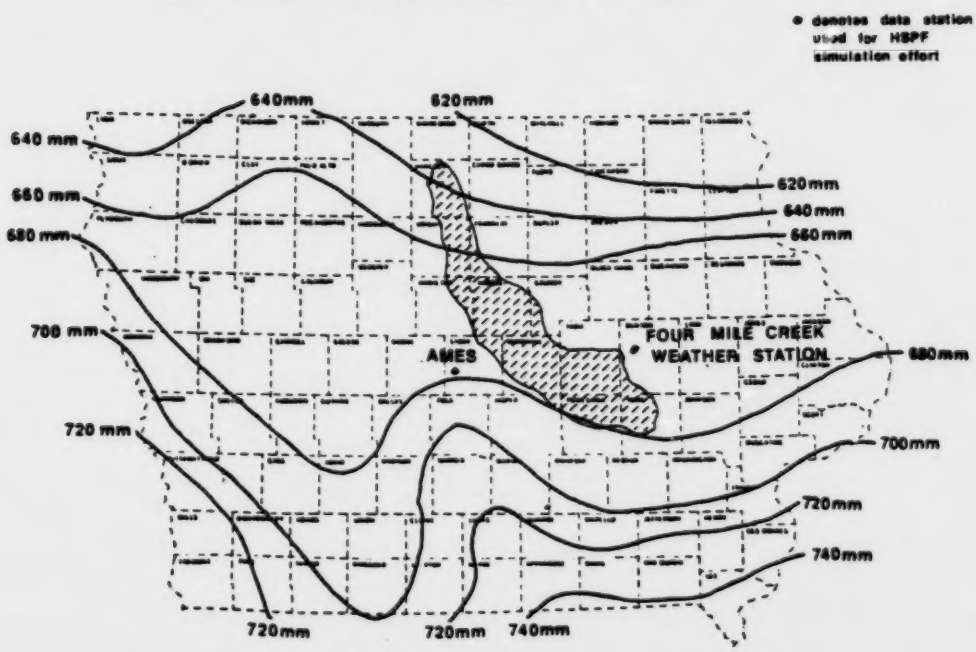


Mean Annual Precipitation in Inches



Mean Annual Potential Evapotranspiration in Millimeters

Figure 2.2 Isopleths of Mean Annual Precipitation and Potential Evapotranspiration in Iowa (adapted from Iowa Natural Resources Council, 1978). Locations of data stations used in simulation are noted on maps.

Potential Evapotranspiration (PET) - Mean annual PET for the Iowa River Basin varies from 635 mm in the north to 686 mm in the far south (Figure 2.2). Three sets of PET data are available: Ames, Iowa City, and Four Mile Creek Weather Station. The record used for simulation was a composite of Four Mile Creek Weather Station and Ames data. All data prior to July 1976 is from Ames, while that occurring after July 1976 is primarily Four Mile Creek Weather Station data, with missing values obtained from Ames. The ten year (1969-1978) average annual PET for the combined record is 630 mm; this suggests that the record may be a little low for the southern portion of the basin. However, since the record was used successfully for the Four Mile Creek simulation, it should be as effective or more effective in representing the PET for the overall basin.

Air Temperature - Long term records indicate a strong relationship between station latitude and mean annual air temperature (Figure 2.3). Short term records show more variability, but indicate that the 1974-1978 period was cooler than typical. Given the fact that the stations which are selected are used to represent temperature characteristics over large areas of land, stations which exhibit reasonably close agreement between long and short term records are more likely to be representive of the large regions. Selection criteria for air temperature records are listed below in order of importance:

1. Three stations are needed, one to represent each of the three basin sections delineated for the precipitation records.
2. Close agreement between long and short term records is desirable.
3. The short term record should be somewhat cooler than long term record.
4. Stations should be within the watershed boundaries.

Based on these criteria the three air temperature records chosen for the Iowa River Basin simulation were Iowa Falls, Marshalltown, and Cedar Rapids.

Iowa Falls - The station is located inside the watershed, and its short term and long term records are similar. The mean annual temperature is about 8.6 degrees C, and the record was used to represent the upper third of the basin.

Marshalltown - The station is located inside the watershed, and its short and long term records are similar, with the short term record somewhat cooler. The mean annual temperature is approximately 9.2 degrees C, and the record was used to represent the middle portion of the basin.

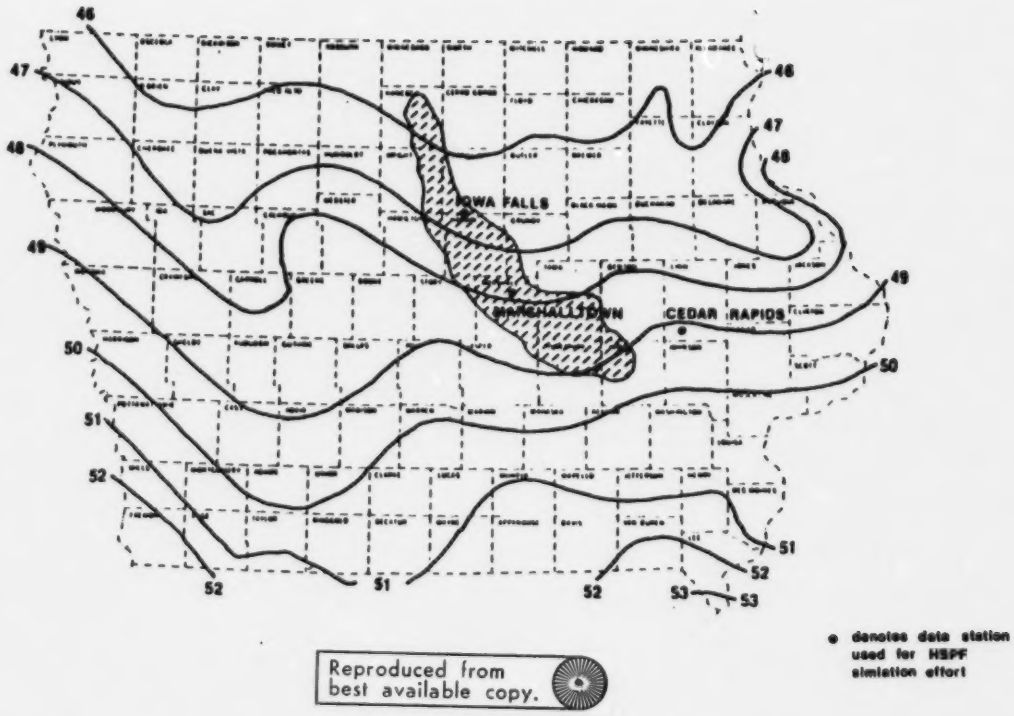


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Figure 2.3 Isopleth of Mean Annual Temperature (°F) in Iowa (adapted from Iowa Natural Resources Council, 1978). Locations of data stations used in simulation are noted on map.

Cedar Rapids - The mean annual temperature of this station is approximately 9.7 degrees C, which makes the station representative of the lower portion of the basin. The short term mean annual temperature is similar but somewhat cooler than the long term record. The station is located outside of the watershed, but appears to better represent the lower third of the basin than any other station.

The quality of all three records is excellent, with a total of seven records missing for the entire simulation period. These records were filled in using data from nearby stations. All records consist of maximum and minimum air temperatures. These data were distributed to hourly values for use by HSPF.

Wind Speed - Wind data for the state of Iowa do not vary greatly from station to station. Consequently, the wind data from Four Mile Creek Weather Station (corrected using Waterloo data), which were used for the Four Mile Creek simulation, were examined to determine whether the record would adequately represent the entire Iowa River Basin. Analysis showed that the mean average hourly wind speed over any given month of the ten year Four Mile Creek record does not vary from the long term composite Iowa value for the same month by more than 1.6 km/hr. Comparison of mean annual wind speeds showed a composite statewide value of 12.2 km/hr at 0.3 meters above the land surface versus a value of 12.1 km/hr for the Four Mile Creek data. The Four Mile Creek record has considerable gaps in it and was updated for the Four Mile Creek simulation using Waterloo data. This composite record was used for the entire Iowa River Basin.

Solar Radiation - Comparison was made between the Four Mile Creek Weather Station solar radiation data and that at Ames (approximately 80 kilometers away) to assess the variability of radiation within the basin area. For the 18-month period from July 1976 to December 1977 the records differed by 3%, with a maximum monthly variation of 20% for the month of March 1977. Given the limited variability in these two records, the radiation record which was used for the Four Mile Creek simulation was used to represent the entire Iowa River Basin. This record is a composite of Four Mile Creek Weather Station and Ames data. All data prior to July 1976 is from Ames, while that occurring after July 1976 is primarily Four Mile Creek Weather Station data, with missing values obtained from Ames.

Dewpoint Temperature - Previous studies have shown similarity between average daily dewpoint temperature and minimum daily temperature. Comparison of these two values on a daily basis for a 60-day record at Waterloo verified this relationship. Given the fact that only one dewpoint record (Mason City) is available near the study basin, it was decided that the best representation of dewpoint temperature could be obtained by using daily minimum temperature records for the stations selected to represent air

temperature for the three basin segments (Iowa Falls, Marshalltown, Cedar Rapids).

Streamflow - Of the nine streamflow records available (Table 2.2), three of the gages are located on the main branch of the Iowa River and were used in the whole-basin calibration. These are:

1. Iowa River near Rowan
2. Iowa River at Marshalltown
3. Iowa River at Marengo

Of the remaining six gages, only one is located in the northern portion of the watershed, which is characterized by glaciated till, potholes, and low runoff. The record from this gage, at the East Branch of the Iowa River at Klemme, was used to develop hydrologic calibration parameters for the northern area. The Salt Creek gage near Elberon, Iowa (Figure 2.1), was used to develop a second set of hydrologic calibration parameters for the southern area.

Water Quality Data - The following water quality data were used for calibration and comparison with simulated water quality values:

(1) Daily sediment loadings collected by the U.S. Army Corps of Engineers at Marengo, 1974-1978.

(2) 28 analyses of ammonia and nitrate near the waterworks plant at Marshalltown performed 1974-1978 and contained in the U.S. EPA STORET data base.

(3) 32 similar analyses of nutrients at Highway 220 bridge north of South Amana, 1974-1978 (STORET).

(4) Limited analyses of the pesticide alachlor at Coralville Reservoir (Schnoor, 1980) and Lake Rathbun (Schnoor et al., 1982).

Summary. Variability in meteorologic patterns and soils characteristics necessitate the division of the Iowa River Basin into three segments in order to perform a reasonable hydrologic simulation. The tentative boundaries of the segments are delineated on Figure 2.5 in Section 2.2 following the discussion of the basin soils characteristics. The streamflow record at the East Branch of the Iowa River at Klemme was used to develop hydrologic calibration parameters for segment #3 and the gage on the Salt Creek tributary of the Iowa River at Elberon was used to develop parameters for segments #1 and #2. The meteorologic data which were used for each segment are summarized in Table 2.3. Additional segmentation of each segment group in order to represent differences in land use will be discussed below.

TABLE 2.3 SUMMARY OF METEOROLOGIC DATA USED TO REPRESENT THE THREE SEGMENT GROUPS OF THE IOWA RIVER BASIN

	Source of meteorologic record used to represent each segment *		
Data Type	Segment #1	Segment #2	Segment #3
Precipitation	Traer	Iowa Falls	Sheffield/ Forest City
Potential Evapotranspiration	FMC**/ Ames	FMC/ Ames	FMC/ Ames
Air Temperature	Cedar Rapids	Marshalltown	Iowa Falls
Wind Speed	FMC/ Waterloo	FMC/ Waterloo	FMC/ Waterloo
Solar Radiation	FMC/ Ames	FMC/ Ames	FMC/ Ames
Dewpoint Temperature	Cedar Rapids (min. daily temp.)	Marshalltown (min. daily temp.)	Iowa Falls (min. daily temp)

* The second station noted in some entries was used to fill in missing data records in the primary station.

** FMC = Four Mile Creek Weather Station

2.2 Land Segmentation

As described above, a preliminary segmentation of the study basin was performed based on meteorologic patterns. In this section the segmentation is refined. Additional factors considered in the final segmentation are soils characteristics, land uses, and boundaries of contributing areas to the river reaches defined for use in the hydraulic routing component of the modeling effort.

Definition of a Segment. For the purposes of HSPF, a segment is defined as a parcel of land which exhibits a homogeneous hydrologic and water quality response. Hence, one set of hydrologic and water quality parameters (both calibration and non-calibration parameters) can be used to characterize all of the land considered as one segment. For modeling purposes, it is not necessary that all of the land in a segment be contiguous. The only requirements are that the segment parameters reasonably represent the hydrologic and water quality characteristics of all land considered as part of the segment, and that the total area of each segment contributing runoff and pollutants to each hydraulic reach is known.

The hydrologic response of a parcel of land is a function of meteorologic patterns, soils characteristics, and land uses. In most cases, meteorologic patterns and soils characteristics allow for a preliminary division of a basin into segment groups. A segment group is a parcel of land which is exposed to meteorologic conditions (rainfall, evaporation, etc.) which for modeling purposes are adequately represented by one set of meteorologic time series. In addition it is assumed that all of the land in the segment group would exhibit a homogeneous hydrologic response if there were uniform land use. In order to make this assumption, soils characteristics must be reasonably consistent throughout the segment group area. Segment groups are subsequently divided into segments, with each segment representing a different land use.

Preliminary segment groups for the Iowa River Basin. Variability in meteorology over the basin indicates that the Iowa River Basin should be divided into three segment groups in order to perform a reasonable hydrologic calibration. Based on long-term isopleth information on rainfall and air temperature, tentative boundaries for the segment groups were formulated, followed by a slight adjustment of boundaries based on spatial distribution of soils.

Most of the Iowa River Basin is covered with prairie soil formed from glacial drift, an unconsolidated mixture of gravel and partly weathered rock fragments left by glaciers. Underlying the drift, at a considerable depth, are consolidated rocks that outcrop where the river has cut deep into the drift. The study area has three distinct topographical areas. The first area is the upper end of the basin above Alden, where topography is gently undulating to nearly level. In this area drainage is poorly

developed, and the land is characterized by depressions which collect water and prevent rapid runoff. Soil associations are predominantly Storden, Clarion, and Webster. Soils characteristics for this association are found in Oschwald et al., 1965.

The second area between Alden and Marshalltown is more hilly terrain, but is still predominantly Clarion and Webster soils. South of Marshalltown the terrain becomes more level, and the glacial drift soils are covered by loess, a silty, wind deposited material. The topography and loess thickness vary in the region; generally 1.5 to 4.5 meters of gently sloping loess materials are present. This southern area is in the Tama-Muscatine soil association (see Oschwald et al., 1965, for soils characterizations).

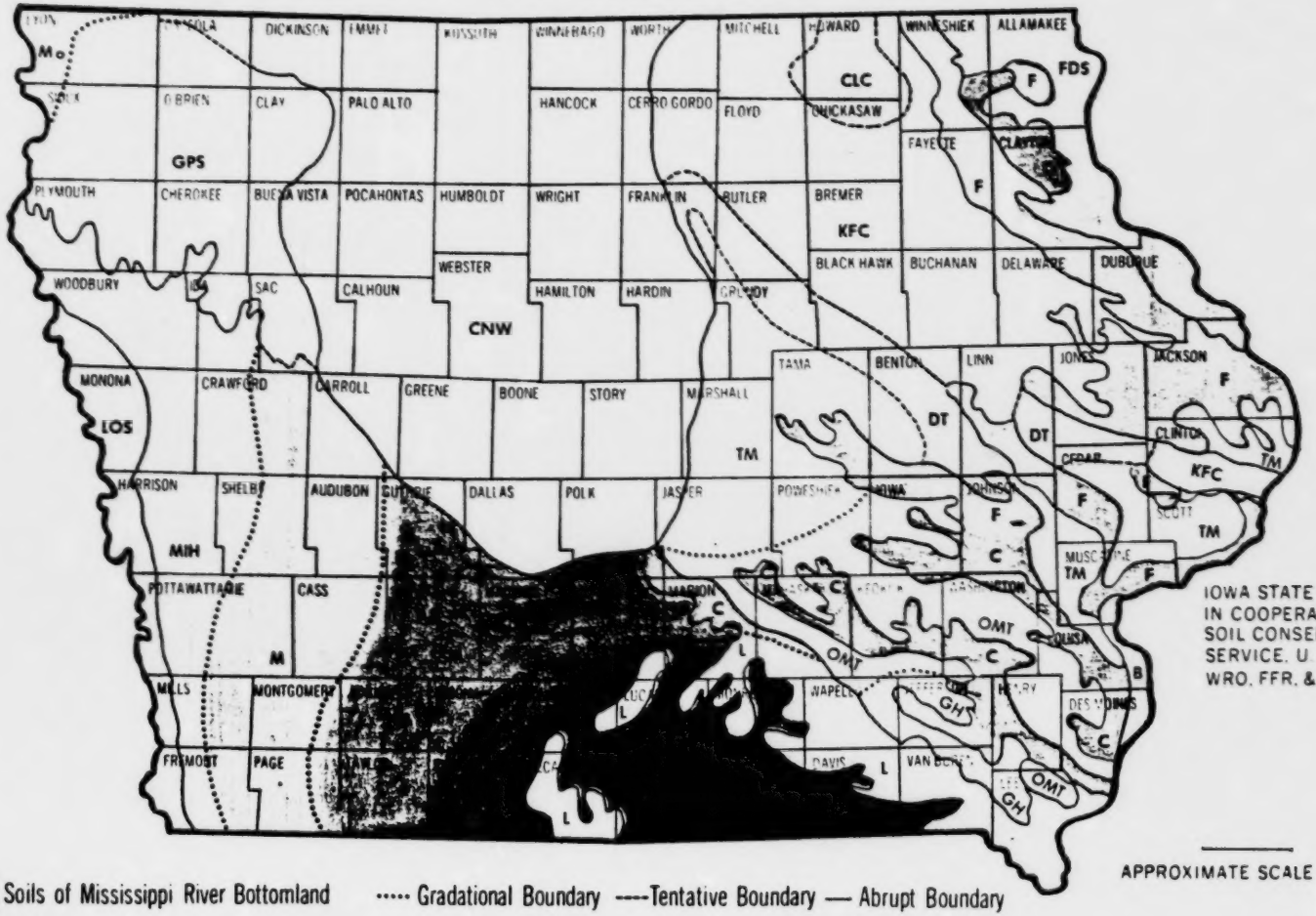
Figure 2.4 identifies the principal soil association areas of Iowa. The boundary between the Clarion-Webster and the Tama-Muscatine areas was compared to the tentative boundary between the bottom two segment groups, as defined by meteorologic considerations. It was concluded that the soils association boundary would serve equally well as a boundary between the land represented by meteorologic data sets # 1 and # 2 (Section 2.1). The preliminary boundary between the two northern segment groups was drawn based on long-term precipitation isohyets and the general breakpoint between the northern flat lands and the central hilly region. These preliminary segment group boundaries are delineated in Figure 2.5.

A good deal of time and effort can be saved by defining segment group boundaries so that they are superimposed on the boundaries between contributing areas to the individual reaches. Contributing area boundaries, as delineated on Figure 2.6, were examined and it was decided that the preliminary segment group boundaries could be shifted and superimposed onto contributing area boundaries as shown on Figure 2.7. Thus, all land contributing runoff to reaches 1-6 is contained in segment group # 1; all land contributing runoff to reaches 7-11 is in segment group # 2, and runoff to reaches 12 and 13 is wholly contributed by segment group # 3.

Land use categories. The final subdivision of segment groups into pervious land segments (PLSs) is based on land use. Land use types which will have the largest impact on runoff or water quality response in the watershed must be identified. For the Iowa River Basin, between 65 and 85% of each county which contributes land to the basin is cropland. As a result, agricultural nonpoint source pollution in the form of fertilizers and pesticides is the major water quality concern in the basin. Of all other land use types, only grassland comprises more than 10% of the area's total usage (see Oschwald et al., 1965, for land use breakdown for Iowa-Cedar River Basin).

A large majority of the croplands in the basin are planted in either corn or soybeans. Given the differences in fertilizer and

FIG. 24 PRINCIPAL SOIL ASSOCIATION AREAS OF IOWA



IOWA STATE UNIVERSITY
IN COOPERATION WITH
SOIL CONSERVATION
SERVICE, U. S. D. A.
WRO, FFR, & RID, 1964

APPROXIMATE SCALE 24 Mi

B Soils of Mississippi River Bottomland ····· Gradational Boundary ----Tentative Boundary — Abrupt Boundary

Adair-Grundy-Haig	Downs	GH Grundy-Haig	MIH Monona-Ida-Hamburg
Adair-Seymour-Edina	DT Dinsdale-Tama	KFC Kenyon-Floyd-Clyde	Mo Moody
C Clinton-Keswick-Lindley	F Fayette	L Lindley-Keswick-Weller	OMT Otley-Mahaska-Taintor
CLC Cresco-Lourdes-Clyde	FDS Fayette-Dubuque-Stonyland	LOS Luton-Onawa-Salix	Shelby-Sharpsburg-Macksburg
CNW Clarion-Nicollet-Webster	GPS Galva-Primghar-Sac	M Marshall	TM Tama-Muscatine

Figure 2.5 Preliminary Segmentation of the Iowa River Basin to Account for Variability in Meteorologic Patterns and Soils Characteristics.

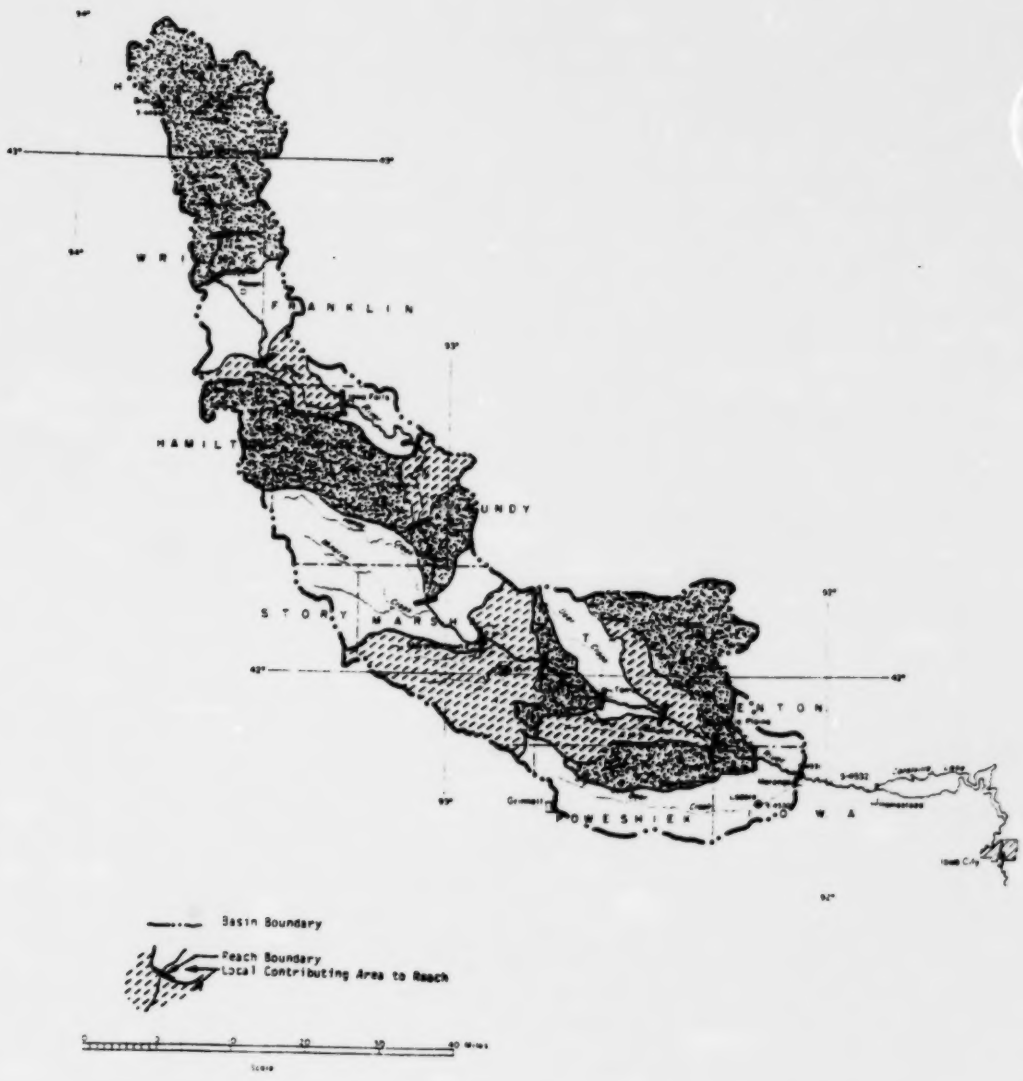


Figure 2.6 Channel Reaches and Contributing Areas for the Iowa River Basin.

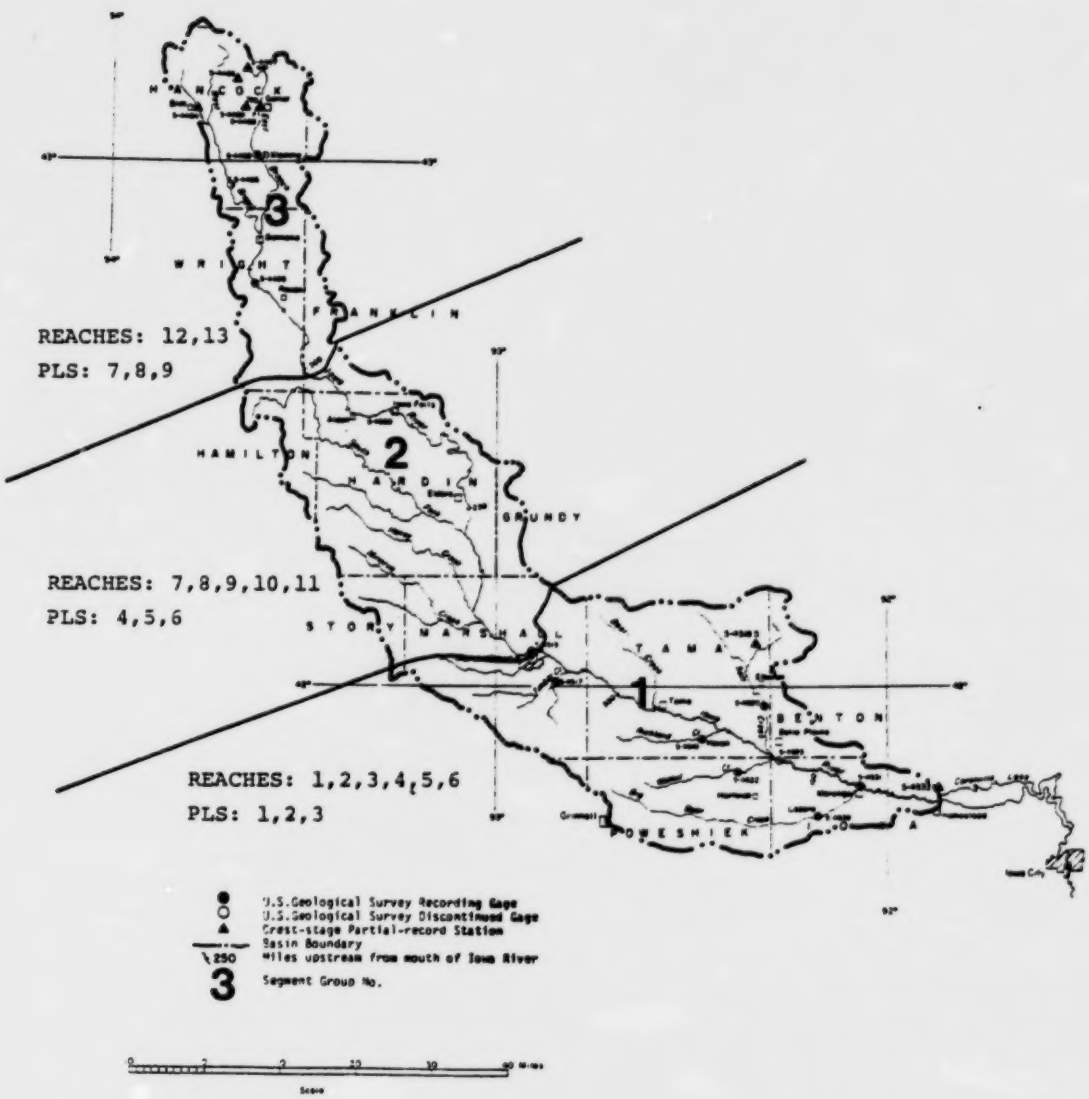


Figure 2.7 Final Segmentation of the Iowa River Basin.

pesticide application for the two crops, it was decided that each crop should be considered as a separate land use type. All lands not planted in corn or soybeans were considered as a third composite land use type. Thus, there were a total of nine pervious land segments (PLSs) for the Iowa River Basin - one to represent each of the three land use types in each of the three segment groups. The characteristics of the nine pervious land segments selected for the Iowa River Basin simulation are summarized in Table 2.4.

Division of segment group areas into PLS areas. County land use data for 1976 from the report 1978 Iowa Agricultural Statistics (Iowa Crop and Livestock Reporting Service, 1978) was reduced to determine the percentage of land in each county devoted to corn, soybeans, and other purposes. It was assumed that the relative amount of land devoted to each use was constant throughout the county. The contributing area to each hydraulic reach was subdivided on a county basis, and further subdivided into corn, soybeans, and other land based on the county-wide statistics. Total area devoted to each of the land uses is summarized in Table 2.5 for each of the 13 subdivisions of the basin. Over the entire basin the estimated breakdown of land use was 45% corn, 22% soybeans, and 33% other uses. The total area of each of the nine pervious land segments is as follows:

PLS	Area (sq km)	PLS	Area (sq km)
1	515	6	655
2	1334	7	490
3	1443	8	707
4	588	9	303
5	1202	TOTAL	7236

2.3 Selection and Characterization of Channel Reaches

The purpose of this section is to outline the criteria used for selection and definition of channel reaches for the 300 kilometers of Iowa River between the confluence of the east and west branches of the river and the U.S.G.S. streamflow gage near Marengo, Iowa.

Channel characteristics

length: 300 kilometers
slope : 0.00044 m/m or 0.44 m/km
flow-through time for mean flow: 7.0 days or 168 hours
velocity at mean flow: 0.5 m/sec or 1.8 km/hr

Definition of reaches. Selection of appropriate reaches for simulation by HSPF requires consideration of the following hydrogeometric parameters:

TABLE 2.4 DEFINITION OF PERVIOUS LAND SEGMENTS FOR IOWA RIVER BASIN

CHARACTERISTICS

PLS#	Meteorology	Soils	Land Use
1	met. set # 1*	loess	soybeans
2	met. set # 1	loess	corn
3	met. set # 1	loess	other
4	met. set # 2	glacial till	soybeans
5	met. set # 2	glacial till	corn
6	met. set # 2	glacial till	other
7	met. set # 3	glacial till	soybeans
8	met. set # 3	glacial till	corn
9	met. set # 3	glacial till	other

* see Table 2.3 for description of meteorologic data

TABLE 2.5 LAND USE IN THE 13 CONTRIBUTING AREA SUBDIVISIONS IN THE IOWA RIVER BASIN

Reach	Contributing area (sq km)	Area planted in corn (sq km)	Area planted in soybeans (sq km)	Other land use (sq km)
1	860	321	111	427
2	847	332	140	376
3	355	140	60	155
4	269	106	47	117
5	238	98	41	98
6	723	337	117	269
7	927	445	197	285
8	995	495	259	241
9	122	62	28	31
10	202	101	49	52
11	199	98	54	47
12	391	184	129	78
13	1109	523	360	225
TOTAL	7236	3243	1593	2400

(1) Reach length. The hydraulic routing algorithms used in HSPF are most accurate when flow time through individual reaches approximates the simulation time step. Since a 2-hour time step was used for routing, reach lengths should ideally have been approximately 3.6 km (1.8 km/hr x 2 hours) in order for flow-through time for mean flow to meet this condition. If this criterion were followed, more than 80 reaches would be necessary for the Iowa River channel. For the purpose of this demonstration project longer reaches, in the range of 15 to 30 kilometers were used. The use of longer reaches reduced and spread out short time interval peaks, but effects were minimal on the mean daily values used for calibration.

(2) Slope. Individual reaches should have reasonably homogeneous bottom slopes. Major drops in bottom elevation due to natural falls or reservoirs should serve as boundaries between reaches; the change in bottom elevation at the channel discontinuity should not be considered in the slope calculation.

A low water profile ior the Iowa River was prepared using U.S.G.S. data (Heinitz, 1973). The profile (Figure 2.8) indicated a highly uniform slope for the entire 300 km stretch of river. A preliminary division of the river into reaches indicated that slopes range from 0.00026 to 0.00069 m/m. Consequently, slope was not a major consideration in reach definition for the Iowa River. U.S.G.S. data indicated only one significant discontinuity in the channel bottom: a 24-foot drop below the Iowa Falls Power Dam (Figure 2.8). The reservoir site was used as a reach boundary in definition of the Iowa River reach configuration.

(3) Entry point of local flows. HSPF assumes that all local flows enter a reach at the upstream boundary. Consequently, it is reasonable to define reaches so that downstream limits are located directly above major tributary inflows. Hence, inflows enter a reach at its upstream limit as assumed by the routing algorithms.

The Iowa River was divided into 13 reaches for simulation. Of the 12 intermediate reach boundaries between the study limits, one was selected at the Iowa Falls Power Dam channel discontinuity, 2 were selected at U.S.G.S. streamflow gage sites (Rowan and Marshalltown), eight corresponded to sites of major tributary inflow, and one was chosen arbitrarily to subdivide a section of river which was too long to be represented as one reach.

Figure 2.8 Iowa River Low-Water Profile

The 13 reaches and the contributing area to each reach are illustrated in Figure 2.6. Reach characteristics including limits, length, channel slope, and contributing area are summarized in Table 2.6.

FTABLE definition. The hydraulic characteristics of each reach must be specified in an FTABLE for use in the HSPF input sequence. FTABLES specify values for surface area, reach volume, and discharge for a series of selected average depths of water in the reach; intermediate values are interpolated.

FTABLES for reaches 1, 7, and 13 were developed using U.S.G.S. cross-sections at gage sites and depth/discharge curves, combined with specified reach lengths. FTABLES for reaches two through six were developed assuming that the slopes of the cross-sections were the same as that at Marengo, but that channel capacity decreased upstream from reach to reach. Both the width and depth coordinates of points on the Marengo cross-section were multiplied by a factor (<1.0) consistent with relative top width data developed by Wallace (1971) for each of the reaches along the Iowa River.

The adjusted cross-sections were input to an auxiliary computer program along with values for channel slope, Manning's n and flow. The program generated values for normal depth, cross-sectional area, and top width for a series of flow values at each reach cross-section, providing all the hydraulic data necessary to generate the FTABLES. The same procedure was used to develop FTABLES for reaches eight through twelve based on the cross-section slope at Rowan. Again, channel capacity was increased downstream from reach to reach by applying progressively larger multipliers (based on Wallace's data) to the coordinates of the Rowan cross-section. It should be noted that the Marshalltown cross-section was not used to generate other FTABLES, because its shape was not considered representative of most stretches of the river (Wallace, 1971).

2.4 Sources of Chemical Loadings to the Iowa River

Pollutants are introduced into the Iowa River by both point and nonpoint sources. Point sources include effluent from municipal sewage systems and industrial plants and runoff from concentrated animal feeding operations. Under normal flow conditions the dilution capacity of the Iowa River is large compared to the volume of effluent from municipal and industrial discharges. According to data collected by the Iowa Department of Environmental Quality (1977), total return flows from point sources to the Iowa River and its tributaries amount to approximately 25 cfs, as compared to a mean flow of 1700 cfs on the Iowa River at Marengo.

TABLE 2.6 REACH CHARACTERISTICS FOR THE IOWA RIVER

Description of Reach	Reach No.	Reach Length (km)	Channel Slope (m/m)	Contributing Area (sq km)
Belmond to Gage at Rowan	13	15.0	.00026	1109
Gage at Rowan to Unnamed Creek Confluence	12	26.4	.00031	391
Unnamed Creek Confluence to Iowa Falls	11	28.8	.00066	199
Iowa Falls to Midpoint	10	28.3	.00069	202
Midpoint to South Fork Confluence	9	28.3	.00055	122
South Fork Confluence to Honey Creek Confluence	8	22.4	.00044	995
Honey Creek Confluence to Gage at Marshalltown	7	16.7	.00047	927
Gage at Marshalltown to Sugar Creek Confluence	6	24.3	.00033	723
Sugar Creek Confluence to Deer Creek Confluence	5	29.8	.00028	238
Deer Creek Confluence to Richland Creek Confluence	4	26.1	.00030	269
Richland Creek Confluence to Salt Creek Confluence	3	20.1	.00032	355
Salt Creek Confluence to Honey Creek Confluence	2	16.3	.00030	847
Honey Creek Confluence to Gage at Marengo	1	17.4	.00026	860
TOTAL		299.8	.00044	7236

Major municipal and industrial discharges are nearly all subjected to some form of primary and secondary treatment (Iowa Natural Resources Council, 1978), and treated effluent is generally well assimilated by the Iowa River. The impact of animal feedlot runoff on river water quality in Iowa has not been assessed quantitatively in previous reports. Since the quality of feedlot runoff water is highly variable, depending on such parameters as rate of rainfall, temperature, feedlot surface conditions, and storage in runoff control systems (Miner et al., 1981), it is difficult to accurately estimate the actual amount and strength of pollutants arriving at the edge of stream. Available resources did not allow quantifying these pollutant contributions within the scope of this preliminary study.

Over 90% of the Iowa River Basin is agricultural land, and consequently, degradation of Iowa River water quality by nonpoint source pollution from farmlands is the major concern. Sediment, nutrient, and pesticide loadings from agricultural runoff have increased significantly during the last two decades due to use of agricultural chemicals, decreased crop rotation practices, and conversion of marginal land to annual crop production.

This modeling effort focused on simulation of sediment, nutrients, and pesticides in the Iowa River Basin. Given the predominance of agricultural activity in the study area, only nonpoint sources from agriculture were considered in this demonstration study. Accurate representation of sediment detachment/transport and chemical application/removal from agricultural lands should provide a reasonable basis for simulation of sediment and pesticide loadings to the Iowa River. However, the nutrient simulation was somewhat incomplete, because nutrient loadings from point sources were not included. Point source loadings can be a significant factor in ambient stream pollutant concentrations during low flow periods such as the 1975-1977 drought years. While some concentration values are questionable without consideration of point sources, simulation of total nutrient loadings for the basin can provide reasonable results given the predominance of nutrient loadings from agricultural croplands.

2.5 Agricultural Practices and Chemical Applications

As noted previously, the primary cause of water quality degradation in the Iowa River Basin is agricultural nonpoint source pollution, particularly nutrient and pesticide runoff from corn and soybean cropland. For the purpose of demonstrating the application of HSPF for simulation of water quality processes and conditions, and the effects of BMPs in a large river basin we modeled the fate and transport of the herbicide alachlor and nitrogen (NO_3, NH_3, and related species) as was done in Four Mile Creek. This section describes the agricultural practices, and the development of the chemical application rates, methods, and

timing which were subsequently used in the pesticide and nutrient simulation runs.

Agricultural Practices. Following the practices inventoried in the Four Mile Creek study, we assumed conventional agricultural practices were predominant in the entire Iowa River Basin. This provided the basis for both the calibration effort and the comparison with the results obtained from simulating a proposed BMP scenario (see Section 4.0). The components and sequencing of operations that comprise our definition of conventional agricultural practices were as follows:

- Fall fertilizer application and moldboard plowing of corn residue
- Spring plowing and disking of soybean stubble and residue
- Spring disking for seedbed preparation on both soybeans and corn; fertilizer application and incorporation by disking on corn
- Planting and herbicide applications following seedbed preparation
- Two field cultivations for weed control in early summer; fertilizer application (side-dressing) coincident with first cultivation on corn
- Crop residues removed or tilled in the fall.

All cropping and tillage operations were assumed to be generally parallel with the slope direction and in straight rows. Spring and summer operations for corn generally preceded corresponding operations for soybeans by about 10 to 15 days based on average crop development information presented by the Iowa Livestock Crop Reporting Service (1978) and experience from the Four Mile Creek study. Also, based on variations in soil temperatures, spring operations in the southern portion of the Iowa River Basin were assumed to precede operations in the northern part; whereas fall operations were assumed to occur earlier in the north.

Pesticide Applications. Alachlor is the principal herbicide applied to corn cropland in Iowa with approximately 40% of the area receiving alachlor either alone or in combination with other herbicides. It is generally applied to the surface in solid form (Monsanto Chemical Co. - Lasso 4E, 50% active ingredient) (Taylor, 1981). The usual application method is preemergence (65-80% of treated area) while 15-30% of the cropland receives alachlor preplant and 1-4% postemergence applications.

The primary herbicide applied to soybean cropland is trifluralin; however, alachlor is applied to approximately 30% of the area and the total amount of alachlor is greater. As with corn, alachlor is usually applied preemergence in solid form.

Alachlor application rates and timing were developed from Iowa State University Cooperative Extension Service survey data (Becker, 1980; Becker and Stockdale, 1980; Jennings and Stockdale, 1980; Harmon and Duncan, 1978). This information included the statewide percentage of cropland receiving chemicals, the application rates of specific commercial herbicides, and combinations of chemicals; the data is further broken down by application method, i.e., preplant, preemergence, and postemergence. Similar data was available for individual agricultural districts in Iowa for the years 1978 and 1979. District 2 includes those portions of the Iowa River Basin in Pervious Land Segments 3, 6, and 9 while District 5 encompasses Land Segments 1, 2, 4, 5, 7 and 8. Additional information for this task was taken from the Four Mile Creek watershed study.

Analysis of available data resulted in the assumption of an annual alachlor application rate of 2.8 kg/ha for both corn and soybean cropland over the entire watershed. The assumption of a single rate for all years and both land uses is due to inconsistencies in the data. The ISU Cooperative Service survey data indicated higher rates for soybeans than corn in Districts 2 and 5 for 1978 and 1979 while the statewide survey and the detailed Four Mile Creek inventories show higher rates for corn. The district and statewide survey rates range between 2.1 and 2.8 kg/ha for 1976, while the more accurate Four Mile Creek inventory data shows a downward trend from 2.8 kg/ha in 1976 to 2.6 kg/ha in 1978.

The question of timing of alachlor applications has a major impact on the resulting simulation. In reality, farmers in the southern portion of the Iowa River Basin typically apply alachlor to corn cropland in early to mid May and soybean cropland in late May to early June. This timetable generally precedes by up to two weeks analogous operations in the northern area of the watershed. In each area, a normal distribution about an average application date can usually be assumed.

HSPF requires the specification of dates and amounts of chemicals applied on each simulation land segment; hence, one cannot specify applications of individual farmers over such a large watershed without incurring tremendously large simulation costs. The assumption of a single application date, time, and amount for a large area results in the simulation of a worst case senario producing unusually high alachlor runoff concentrations and loadings at the first runoff event following application. For this reason, the total application amount was divided into three separate applications corresponding to 25%, 50%, and 25% of the total rate, and separated by 5-10 days. This triangular

distribution was adopted from the Four Mile Creek simulation effort, and is intended to approximate the normal distribution actually occurring in the field by many different farmers. Table 2.7 lists the target dates and amounts of alachlor applications assumed for soybeans and corn segments in the Iowa River Basin; actual application dates for each year in the simulation period were adjusted if necessary to avoid chemical applications on days when rainfall occurred.

Ideally, the 3 separate applications would best be represented by 3 separate land segments corresponding to each of the areas receiving alachlor applications on different dates and at the total application rate (i.e, 2.8 kg/ha). However, this type of representation would result in more than a tripling of the simulation costs due to the additional land segments that would need to be simulated. Consequently, the applications were divided as shown in Table 2.7 in an attempt to develop a reasonable approximation of the alachlor application distribution actually occurring in the field, while minimizing the resulting computer costs.

Only 25-50% of the total cropland in the Iowa basin actually receives alachlor each year. Thus, the unit area (per hectare) alachlor loadings calculated in the land surface simulation were multiplied by only the amount of land area receiving alachlor to determine the actual stream loading of chemical. These areas were determined by observing downward trends in the actual statewide percentages from 30 to 22% for soybeans and 52 to 41% for corn over the period 1976 to 1979. Since our simulation covered the years 1974-1978, and data for 1974-1975 was unavailable, it was assumed that 30% of soybean cropland and 50% of corn cropland throughout the basin received alachlor during the entire simulation period.

Fertilizer Application. Nitrogen fertilizer application amounts were developed primarily from USDA survey data (Harmon and Duncan, 1978; Moss, 1981) which summarizes the annual practices of 150-200 farms in Iowa. Additional information was derived from surveys by Iowa State University as part of the Four Mile Creek watershed study. Table 2.8 summarizes the usage of nitrogen fertilizers for corn and soybeans in Iowa for the years 1974-1978.

A problem unique to the nutrient simulation results from the fact that nutrients are contributed from all land within the watershed whether or not the land receives fertilizer applications. Consequently, each of the nine simulation land segments would have to be divided into two segments to account for land receiving and not receiving fertilizer. However, total nitrogen applied to soybeans in Iowa annually is a small fraction (0.3-0.6%) of that applied to corn. Likewise, total nitogen usage on other crops and pasture in Iowa is also very small relative to corn. For this reason, we assumed nitrogen

TABLE 2.7 TIMING AND AMOUNT OF ALACHLOR APPLICATIONS ASSUMED IN THE IOWA RIVER BASIN (kg/ha)

	SOYBEANS			CORN	
	Target Date	Amount		Target Date	Amount
PLS 1	May 25	0.70	PLS 2	May 1	0.70
	June 3	1.40		May 10	1.40
	June 10	0.70		May 20	0.70
	Total	2.80		Total	2.80
PLS 4	May 30	0.70	PLS 5	May 5	0.70
	June 7	1.40		May 15	1.40
	June 15	0.70		May 25	0.70
	Total	2.80		Total	2.80
PLS 7	June 5	0.70	PLS 8	May 10	0.70
	June 13	1.40		May 20	1.40
	June 20	0.70		May 30	0.70
	Total	2.80		Total	2.80

TABLE 2.8 ACTUAL NITROGEN FERTILIZER USAGE ON CORN AND SOYBEAN CROPLAND IN IOWA, 1974-1978.

	Hectares Harvested	Percent N-Fertilizer	Rate (kg/ha-N)	Total N * Applied (tonnes*1000)
Corn				
1974	4,755,000	89.7	114.0	486.
1975	4,910,000	N.A.	114.6	-
1976	5,160,000	97.9	141.3	714.
1977	5,585,000	98.1	143.5	786.
1978	5,382,000	93.4	145.5	731.
Soybeans				
1974	2,860,000	6.5	9.4	1.75
1975	2,820,000	N.A.	10.2	-
1976	2,650,000	6.5	13.9	2.39
1977	2,910,000	11.0	15.1	4.83
1978	3,070,000	9.9	12.4	3.77

N.A. - Not available
* - Approximate value calculated from the data in columns 1-3.

Sources: Harmon and Duncan, 1978; Moss, 1981.

applications occurred only on corn cropland, and further that 100% of the corn cropland received nitrogen fertilizer (actual value is approximately 95%). This assumption, while reducing greatly the computational complexity and costs of the simulation, has a very small effect on the total nonpoint source loading of nitrogen nutrients to the Iowa River. In addition, since the available data consisted of statewide averages, no distinction could be made for fertilizer usage in different portions of the basin, i.e., a single application rate was assumed for all corn land segments.

Analysis of the available data resulted in the adoption of an annual fertilizer nitrogen application rate of 140 kg/ha on the corn cropland. This includes 132 kg/ha from the applied fertilizer data (weighted average), and an additional 8 kg/ha to account for nitrogen contributed by rainfall, based on estimates obtained from the Four Mile Creek study. Assumed distribution and timing of nitrogen fertilizer application included 20% application in the fall incorporated by fall plowing, 50% application in spring incorporated by disking, and 30% application in the summer. Table 2.9 shows the target dates, amounts, and incorporation methods of nitrogen applications assumed for the three corn land segments in the Iowa River Basin; as noted previously, actual dates in each year were adjusted if necessary to avoid fertilizer applications on days when rainfall occurred.

The distribution of chemical application amounts within the soil profile resulting from application and/or incorporation methods is another important aspect of modeling agricultural nonpoint pollutant loadings. Surface applied chemicals are available at relatively high concentrations for transport by surface runoff, soil erosion, and leaching; whereas incorporated chemicals are generally available at much lower concentrations for surface transport mechanisms and higher concentrations for subsurface flow components. Thus the chemical distribution in the soil, in addition to adsorption and soil characteristics, affects the relative magnitudes of chemicals moved by surface and subsurface mechanisms.

In this study, we assumed that alachlor was applied in a pre-plant surface application, and nitrogen fertilizer was incorporated in the adsorbed ammonia form by the methods listed in Table 2.9. For the various tillage methods considered in this study, the chemical distribution between the surface (0 to 0.5 cm) and upper (0.5 to 15 cm) soil zones was based on an investigation into the effects of BMPs on HSPF parameters (Donigian et al., 1983a) and experience gained in the Four Mile Creek study. The following distributions were assumed:

TABLE 2.9 AMOUNT AND TIMING OF NITROGEN FERTILIZER APPLICATIONS ASSUMED ON CORN CROPLAND IN THE IOWA RIVER BASIN.

	Amount (kg/ha)	Method of Incorporation	Target Date PLS #2	PLS #5	PLS #8
Fall	28.	Plowing	Nov. 15	Nov. 7	Nov. 1
Spring	70.	Disking	April 25	April 30	May 7
Summer	42.	Field cultivation	June 10	June 15	June 20
Total	140.				

Tillage Method	% of Application	
	Surface	Upper
Moldboard plow	0%	100%
Chisel plow	50%	50%
Disking	20%	80%
NH3 Injection	0%	100%
Cultivation	40%	60%

Summary. This section has presented and discussed our assumptions in characterizing and segmenting the Iowa River Basin for simulation by HSPF based on available data. Although we feel our assumptions are reasonable for the purpose of this demonstration study, other investigations of this basin with different goals and objectives will require a re-evaluation of our assumptions. The primary purpose of this section was not simply to justify our assumptions, but to describe the required information and the overall procedures for characterizing and segmenting a river basin for modeling purposes.

SECTION 3

SIMULATION OF THE IOWA RIVER BASIN

The process of applying HSPF to a basin-scale agricultural watershed to evaluate agricultural nonpoint source pollution and resulting water quality involves the integrated modeling of soil, land surface, and instream processes. For the purposes of this demonstration project, a limited calibration effort was necessary to develop a reasonable fit between simulated results and data available for the study area. This calibration effort was necessary to demonstrate sufficient agreement between model results and available data so that the model could then be used for BMP analysis and evaluation (Section 4). This section describes the calibration/simulation process for hydrology and water quality, and the results of this work in modeling the integrated effects of runoff, pollutant generation, and instream processes for flow, sediment, pesticides, and nutrients.

3.1 Hydrologic/Hydraulic Modeling

HSPF module sections SNOW, PWATER, and HYDR were used to perform the hydrologic/hydraulic simulation of the Iowa River Basin. SNOW simulates the accumulation and melt of snow based on energy balance calculations and input meteorologic data. PWATER simulates the land surface and soil processes of the hydrologic cycle including interception, surface detention, soil moisture storage, surface runoff, infiltration, interflow, evapotranspiration, percolation to groundwater, and groundwater outflow. As a final step HYDR was used to perform hydraulic channel routing of runoff. Details of the algorithms and modeling strategies contained in these module sections are fully described in the HSPF User's Manual (Johanson et al., 1981).

Hydrologic simulation of the 7200 square kilometer watershed was performed by modeling 3 segment groups, each of which was represented by one set of meteorological data (Section 2.1). Each segment group was divided into 3 pervious land segments to allow refinement of model parameters to properly represent differences in the hydrologic response of the major land use categories: soybeans, corn, and pasture/other lands (Section 2.2).

Meteorologic data and parameter development. As a first step, parameter values developed to describe soil characteristics and the effects of agricultural activity in the Four Mile Creek watershed (Donigian et al., 1983b) were applied to corresponding segments in the Iowa River Basin. Initial hydrologic simulations were performed on two test watersheds, one in the northern extreme of the basin (East Branch above Klemme, Iowa) and one in the south in the area nearest to Four Mile Creek (Salt Creek

above Elberon, Iowa). Figure 3.1 provides the location of these two watersheds, drainage area information, and a summary of meteorologic and streamflow data used for simulation.

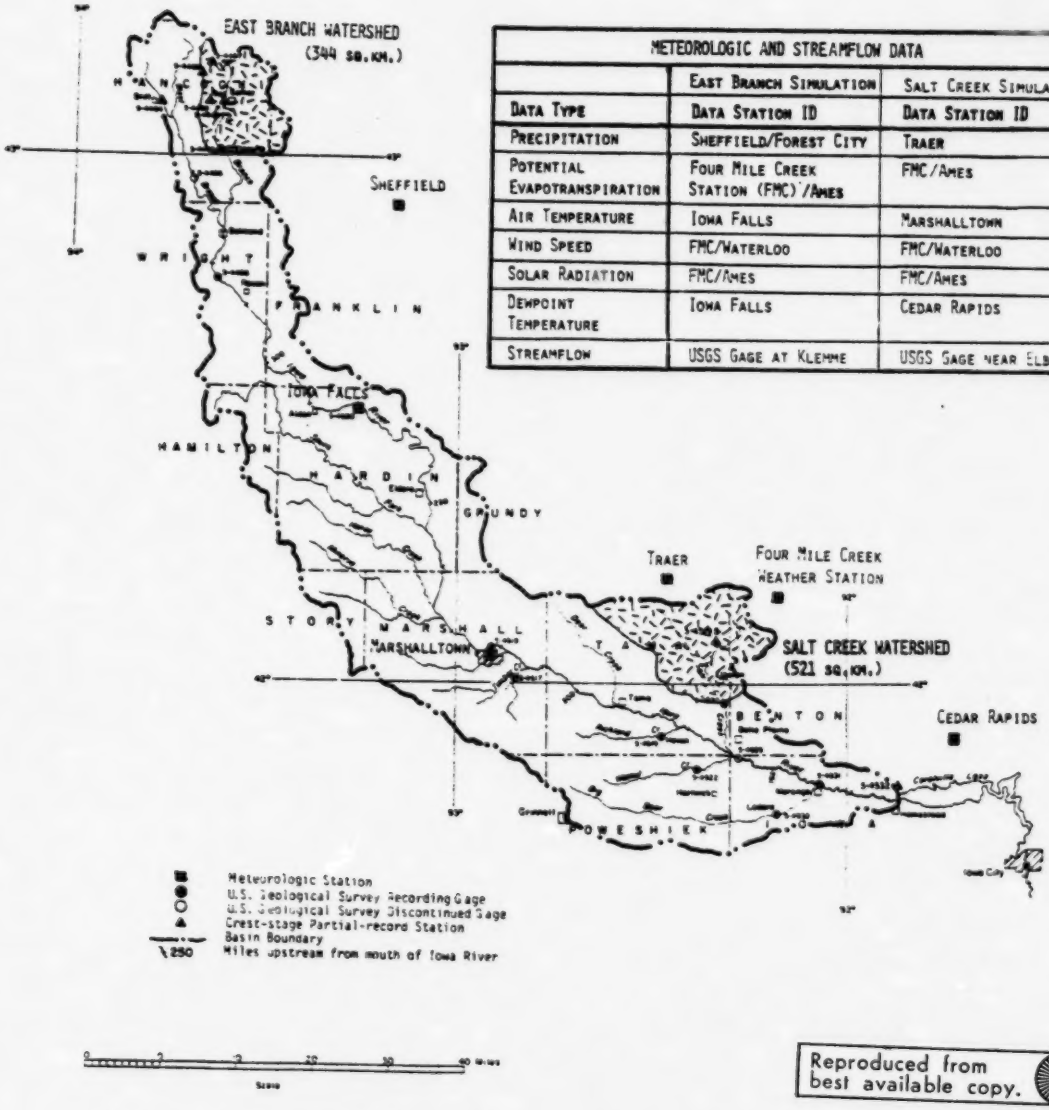
The purpose of the test watershed simulations was to determine differences in local hydrologic response prior to simulating the entire watershed. Differences in soils and topography between the upper and lower parts of the basin are outlined in Section 2.2. Heinitz (1973) characterizes the upper part of the watershed as flat land with many depressions that collect water and retard runoff. From the vicinity of Alden (river km. 460) downstream, the topography becomes a hill and valley landscape, more similar to Four Mile Creek. Given the differences between the northern area and the remainder of the basin, it was expected that significant changes would be necessary to the hydrologic parameter values, particularly for the northern group. Hydrologic simulation of the test watersheds resulted in oversimulation of runoff in the East Branch watershed and under-simulation of runoff in the Salt Creek watershed. Based on the simulation results, the following adjustments to Four Mile Creek parameter values were made prior to the first simulation of the entire basin:

1. Upper zone nominal storage (UZSN) was increased for the upper segment group and decreased for the middle and lower segment groups. This change was consistent with the differences in surface topography. Depressions in the northern area tend to promote surface ponding and greater moisture retention requiring higher UZSN values.

2. The index to infiltration capacity (INFILT) was increased for the upper segment group and decreased for the lower two segment groups. This change was based on soils characteristics, with the sandy soils of the upper segment group characterized by greater infiltration rates.

3. The lower zone nominal storage (LZSN) was increased in the upper segment group and decreased in the lower two segment groups. An increase in LZSN results in a corresponding increase in evapotranspiration and hence less runoff.

Additional adjustments were necessary to the meteorologic data for the whole-basin simulation. Given that three sets of meteorologic data were used to represent over 7200 square kilometers of land, it was essential that the data used for a particular segment group be representative of <u>average</u> meteorologic conditions over the segment group. The precipitation data, which are the most important determinant of simulated runoff, and the air temperature data, which determine the timing of snowmelt, are of particular concern. Consequently,



METEOROLOGIC AND STREAMFLOW DATA		
	East Branch Simulation	Salt Creek Simulation
Data Type	Data Station ID	Data Station ID
Precipitation	Sheffield/Forest City	Traer
Potential Evapotranspiration	Four Mile Creek Station (FMC)/Ames	FMC/Ames
Air Temperature	Iowa Falls	Marshalltown
Wind Speed	FMC/Waterloo	FMC/Waterloo
Solar Radiation	FMC/Ames	FMC/Ames
Dewpoint Temperature	Iowa Falls	Cedar Rapids
Streamflow	USGS Gage at Klemme	USGS Gage near Elberon

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Figure 3.1 Location of East Branch and Salt Creek Hydrology Test Watersheds. Summary of meteorologic and streamflow data used for simulation is included.

isopleth maps for precipitation and temperature were used to compare long-term meteorologic patterns in each segment group to mean characteristics at each of the stations used for the simulation. For each segment group two multipliers (one for precipitation, one for temperature) were developed and applied to all data from the stations for each segment group. The multipliers are listed below:

	Meteorologic Representation
upper segment group	0.95 * Sheffied/Forest City precipitation data
	0.88 * Iowa Falls air temperature data
middle segment group	0.98 * Iowa Falls precipitation data
	0.92 * Marshalltown air temperature data
lower segment group	1.03 * Traer precipitation data
	0.98 * Cedar Falls air temperature data

Agricultural lands in Iowa demonstrate considerable seasonal variation in hydrologic response, due to weather patterns, tillage activities, and land cover/crop canopy changes. The following assumptions were made in representing seasonal changes in the study basin:

1. Seasonal variation in land surface conditions was modeled by providing monthly values for interception storage, upper zone nominal storage, Manning's n for the overland flow path, and lower zone evapotranspiration.

2. The Special Actions section of HSPF was used to decrease infiltration for frozen ground conditions occurring between the winter freeze and spring thaw periods according to the following schedule:

   upper segment group
   spring thaw: 4/15
   winter freeze: 12/1

   middle segment group
   spring thaw: 4/7
   winter freeze: 12/8

   lower segment group
   spring thaw: 3/31
   winter freeze: 12/15

3. The Special Actions routine was also used to increase the infiltration parameter for the effects of tillage on soybean and corn land beginning with the first tillage in the spring; the infiltration parameter was

subsequently decreased to the nominal background value in later summer after compaction had negated the effects of tillage. The dates for both the spring and late summer adjustments were later in the northern watershed area and earlier in the southern area to coincide with the timing of tillage operations.

Simulation time step. Prior to the whole-basin simulation, an analysis of the effect on surface runoff of using a one-hour, two-hour, and four-hour simulation time step was performed on the Salt Creek test watershed. The results indicated that simulated surface runoff decreases with increasing length of time step, while the total runoff (i.e., surface, interflow, and groundwater) remains essentially unchanged. For a two-year period, simulation with a two-hour time step resulted in a 5-10% reduction in surface runoff compared to a one-hour time step; a four-hour time step produced about 30% less surface runoff than the one-hour time step. Based on these results we decided that a two-hour time step would be acceptable for the Iowa River Basin simulation.

Hydrologic calibration. A brief hydrologic calibration effort (3 simulation runs) was made to further adjust parameter values until an acceptable whole-basin hydrology simulation was obtained. These adjustments were necessary primarily to refine the simulation of groundwater recession and flow processes. Final values for all parameters are included with the HSPF input sequences and data base provided to the EPA Environmental Research Laboratory, Athens, GA upon project completion.

Table 3.1 provides yearly comparisons of recorded and observed runoff, in millimeters, at the three U.S.G.S. streamflow gages along the Iowa River (Rowan, Marshalltown, and Marengo), and representative results for simulated mean daily flow are shown in Figure 3.2. Simulated runoff volumes for the first four years of the study period were generally fair to good at the three gages. While records are incomplete at Rowan, it appears that the final set of hydrologic parameter values resulted in a fairly consistent oversimulation of runoff by approximately 15-20% prior to 1978 (Flow records are incomplete for the drought years 1976 and 1977). At Marshalltown and Marengo simulated runoff was less than observed values during the 1974-1977 period. Undersimulation at Marshalltown was generally in the range of 20-25% of observed annual totals while the 5-year total was within 3% of observed runoff. A much closer fit between simulated and observed values was obtained at Marengo with less than a 5% difference for 1975-1977 totals, and only a 4% difference for the entire simulation period.

Runoff for the final year (1978) of the simulation period was drastically oversimulated due to problems with the Sheffield precipitation record which was used to represent the upper

TABLE 3.1 IOWA RIVER BASIN HYDROLOGY SIMULATION RESULTS (expressed as runoff in millimeters).

	Rowan		Marshalltown		Marengo	
Year	OBS	SIM	OBS	SIM	OBS	SIM
1974	154.4	182.6	312.7	232.4	390.7	321.3
1975	152.1	124.2	215.6	169.4	233.9	227.6
1976	58.9*	80.0	135.9	107.2	139.4	138.2
1977	9.4*	47.8	65.5	67.3	98.3	94.7
1978	101.9	299.5	169.2	297.2	227.1	347.5
TOTAL	476.7*	734.1	898.9	873.5	1089.4	1129.3

OBS - observed
SIM - simulated
* does not include 10/76 - 6/77 runoff (observed data not available)

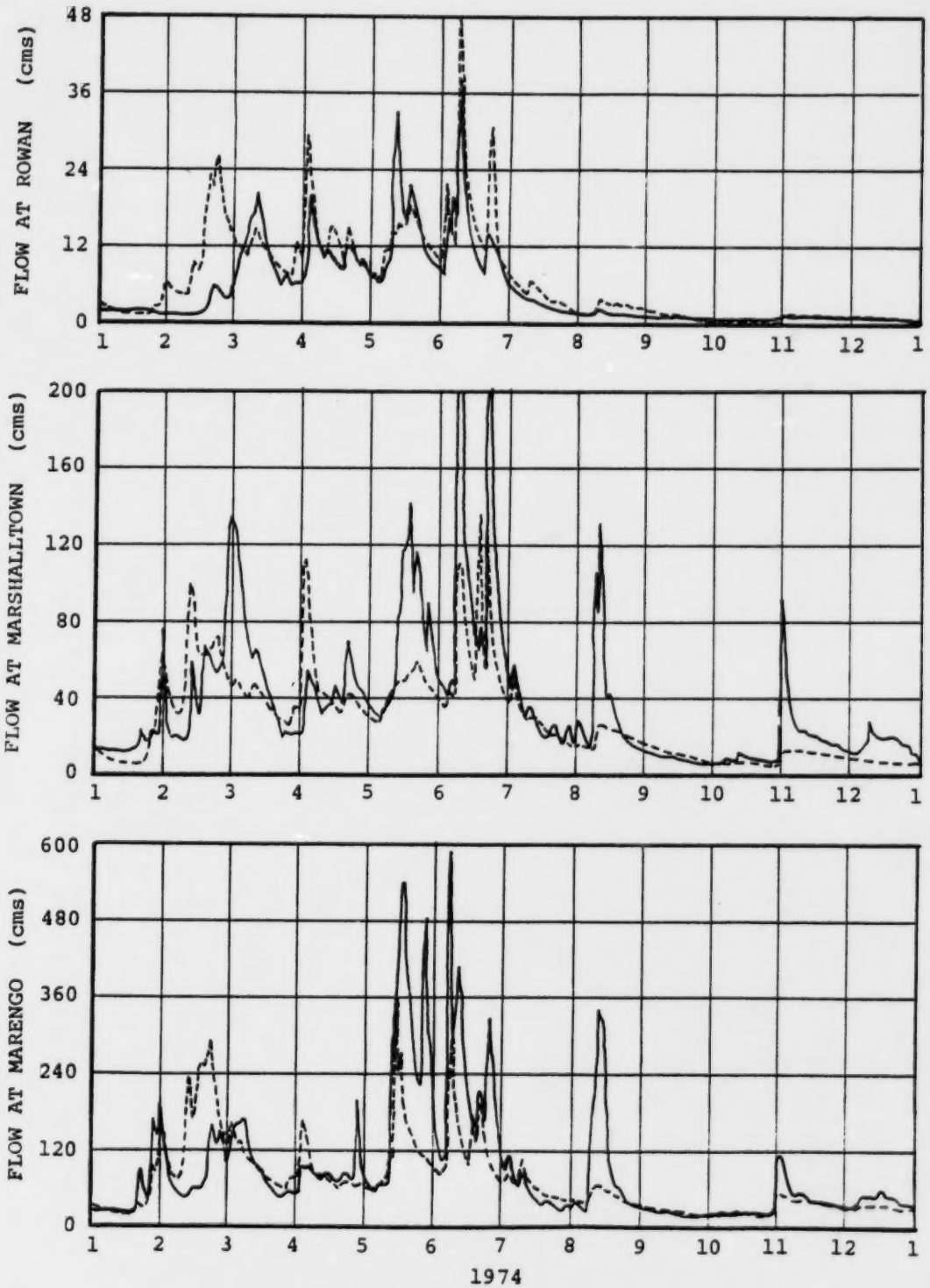

Figure 3.2 Comparison of Flow Simulation Results with Streamflow Records at Rowan, Marshalltown, and Marengo, Iowa.

segment group. Recorded precipitation at the Sheffield gage for June - July amounted to 409 mm, as compared to 211 mm at Iowa Falls and 224 mm at Traer. As a result, the runoff total for the two-month period simulated at Rowan was 135 mm as compared to an observed total of 41 mm. This discrepancy between simulated and observed runoff illustrates the problems associated with using one rainfall record to represent a large segment of land, in this case 1500 square kilometers.

At the Sheffield gage one storm on June 14-15 resulted in 84 mm of rainfall in 12 hours, and another storm on July 5-6 contributed 114 mm in 5 hours. While the recorded rainfall at Sheffield for these events may be accurate, it is unlikely that rainfall of comparable intensity occurred on the entire segment. Overall, simulated runoff for 1978 at Rowan was 190% greater than observed runoff; there was a corresponding 76% oversimulation downstream at Marshalltown and 53% oversimulation at Marengo. It is evident from 1974-1977 results that the 1978 simulation problems are due primarily to non-representative rainfall, and are not a result of inappropriate values for hydrologic parameters. A good fit to observed runoff could only be obtained by adjusting input precipitation for the 1978 period for the upper watershed, based on observed records at surrounding stations.

Another major problem with the hydrologic simulation was the timing and volumes of snowmelt runoff. Modeling snow accumulation, melt, and resulting runoff is a traditional weakness in watershed modeling; more research, algorithm development, and data is needed to better represent the full spectrum of relevant processes. For example, the occurrence and effects of frozen ground conditions are not well understood quantitatively, but they exert major impact on snowmelt runoff. As noted previously, we reduced infiltration during the winter months in an attempt to account for frozen ground effects. As shown in Figure 3.2, simulated runoff from snowmelt generally precedes recorded values; similar results were obtained in the Four Mile Creek study. In most years, the snow pack melts in a short 2 to 3 week period producing a peak flow in about mid-March; the model generally produces a more gradual melting and lower peak flows. These problems are likely due to deficiencies in both the model (e.g., frozen ground, storage of melt in the snow pack) and the input meteorologic data, primarily air temperature and solar radiation. Calibration is usually directed to reproducing observed runoff volumes during the winter period, and approximating the timing of runoff to the extent possible. The goal is to adequately model soil moisture conditions at the end of the winter period so that subsequent runoff events in early spring and summer can be accurately modeled. In this regard, the snowmelt simulation on the Iowa River Basin was adequate for the purposes of this study.

Hydraulic routing. Based on the channel configuration and characteristics developed in Section 2.3, module section HYDR was used to perform kinematic wave routing of runoff in the 300 kilometers of the Iowa River channel above Marengo. HYDR generated values for average daily flow at 13 points along the channel based on simulated runoff. Three of these 13 points were Rowan, Marshalltown, and Marengo, and consequently a direct comparison could be made between simulated flows and the U.S.G.S. gage records at these sites. Significant discrepancies in both timing and magnitude of flow resulted from the problems with snowmelt simulation and rainfall data previously mentioned.

Figure 3.2 compares simulated and observed mean daily flows for 1974 at Rowan, Marshalltown, and Marengo. While a better fit between simulated and observed results was obtained for several of the gages during other portions of the simulation period, the 1974 results were selected to illustrate several points. Timing discrepancies between simulated and observed flows are evident at all three gage sites and result from superimposing the timing of rainfall at one weather station onto large areas of land which experience variable timing of rainfall. Such problems with timing preclude the accurate modeling of individual flow events, but do not preclude simulation of reasonable annual water balances.

A more serious problem is illustrated by the August storm in the middle and lower portions of the basin. In this case the recorded rainfall at the Iowa Falls and Traer stations is not nearly large enough to induce the 340 cms peak recorded at Marengo. Apparently, a major storm passed through the basin resulting in significant rainfall over large portions of the middle and lower basins while only a small amount of rainfall occurred at the weather stations used to represent the basin for simulation purposes.

For the purposes of this demonstration project, comparison of recorded and simulated flow frequency data provides an adequate indication of the acceptability of the simulation results. Figure 3.3 shows the simulated and observed flow frequency curves for the 1974-1978 period at Rowan, Marshalltown, and Marengo, and Table 3.2 provides a simple statistical comparison of simulated and observed values for mean daily flows at the three gage sites.

Both Figure 3.3 and Table 3.2 indicate that modeling results for the upstream gage at Rowan were not good. Simulated mean flow was over 50% greater than observed mean flow, and the maximum value simulated for mean daily flow was almost five-fold larger than the observed maximum. However, since only 15% of the basin area is above the Rowan gage, simulation results for this gage are not as important as results at the downstream gages at Marshalltown and Marengo. At the lower gages simulated flows had a much better fit to observed values. Mean simulated flows at both gages differed from mean observed flows by less than 5%, and

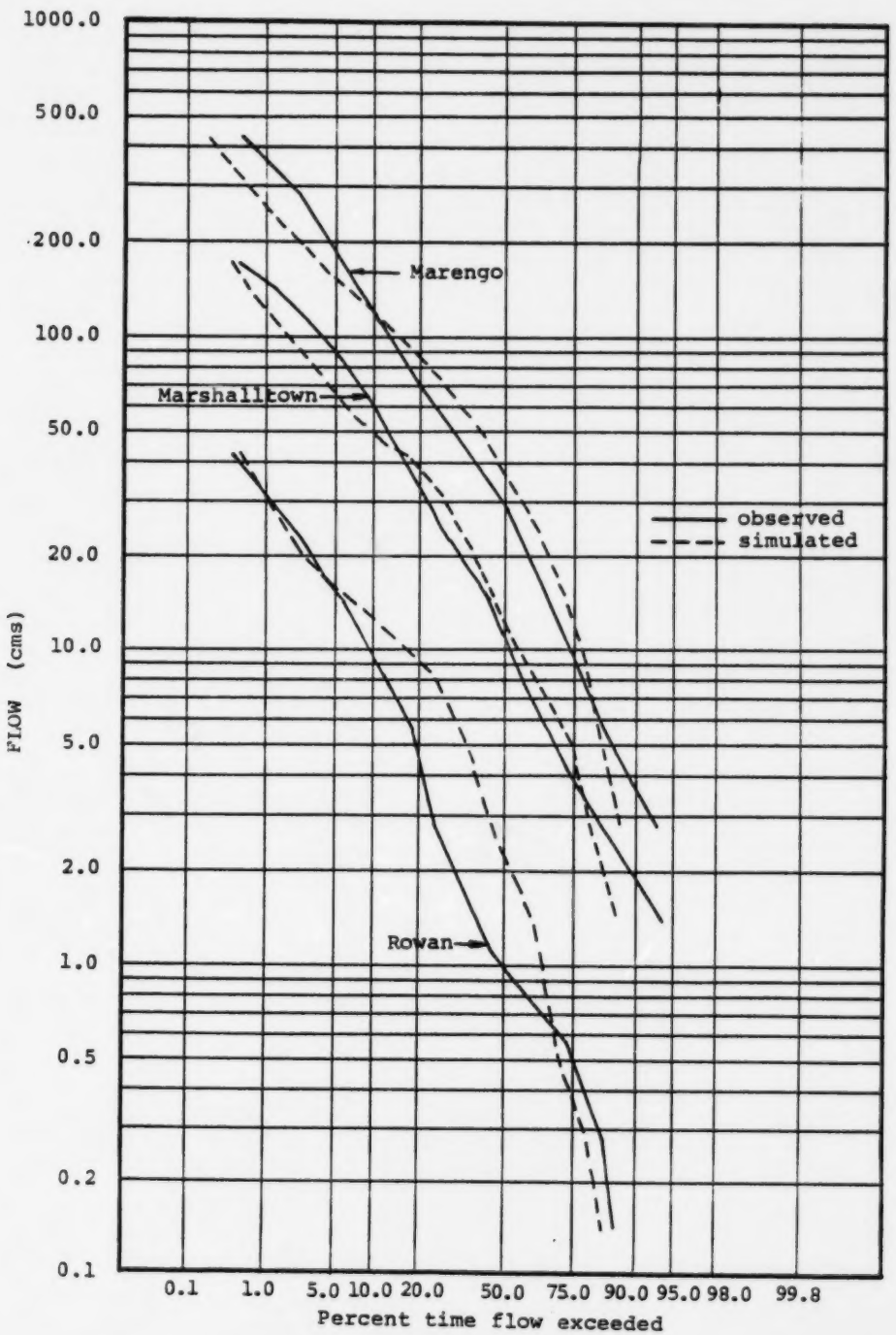

Figure 3.3 Comparison of Simulated and Observed Flow Frequency at Rowan, Marshalltown, and Marengo, Iowa (1974-1978).

TABLE 3.2 STATISTICAL COMPARISON OF SIMULATED AND OBSERVED MEAN DAILY FLOW AT ROWAN, MARSHALLTOWN, AND MARENGO

	Flow at Rowan (cms)		Flow at Marshalltown (cms)		Flow at Marengo (cms)	
	OBS	SIM	OBS	SIM	OBS	SIM
Mean	3.37	5.15	22.5	21.8	50.0	51.8
Standard Deviation	6.68	12.3	32.4	27.7	68.8	56.7
Maximum	90.0	431.5	376.6	439.2	557.8	586.2
Minimum	0	0	0.1	0.06	0.7	0.1

OBS - observed
SIM - simulated

simulated maximum flows were no more than 20% larger than observed maximums. While these statistics verify that the simulated flows are acceptable for the purposes of this study, additional calibration is recommended if the information developed in this study is to be used for planning decisions in the study basin.

3.2 Watershed Sediment Modeling

Module section SEDMNT was used to simulate the detachment and removal of sediment from the Iowa River Basin based on input rainfall, simulation of overland flow, and input model parameters describing the soil characteristics and land surface conditions. The following assumptions were made in representing erosion processes:

1. Gully erosion was not simulated.

2. Monthly fractions for erosion-related cover for corn fields, soybean fields, and pasture/other lands which were previously developed for the Four Mile Creek watershed were applied directly to the Iowa River Basin.

3. It was assumed that tillage practices, which significantly affect the availability of detached sediment, were uniform in all but timing for a given crop (corn or soybeans). Thus, soybean fields throughout the basin were assumed to be plowed, disked in early spring, and then cultivated for weed control twice in June and July each year. Corn fields were assumed to be plowed in November of each year, disked in April, and cultivated twice as for soybeans. It was assumed that all other land was not tilled.

4. The timing of agricultural practices for the lower third of the basin (segments 1, 2, 3) was assumed to be the same as the generalized timing of operations on the Four Mile Creek watershed:

Beans	Corn
plowing - April 15	disking - April 25
disking - May 15	first cultivation - June 11
first cultivation - June 21	second cultivation - July 1
second cultivation - July 14	plowing - November 15

For the middle portion of the basin (segments 4, 5, 6) spring and summer activities for soybeans and corn were assumed to occur one week later than in the lower basin, and the fall plowing on corn fields one

week earlier. Tillage activities on the upper basin area (segments 7, 8, 9) followed a similar pattern, with two weeks variation from the lower basin.

As a first step, erosion parameter values developed in the Four Mile Creek study were applied to the Iowa River Basin due to similarities in relevant soils characteristics. Since recorded sediment erosion data were not available anywhere in the study area, adjustments to parameter values, and resulting adjustments to simulated erosion were made on an intuitive basis. The simulated erosion from the basin resulting from use of the Four Mile Creek parameter set was initially too low; consequently the following adjustments were made:

1. Soil detachment by rainfall was enhanced in all segments by increasing the value of the coefficient (KRER) in the soil detachment equation.

2. Washoff of sediment was enhanced by increasing the value of the coefficient (KSER) in the soil washoff equation.

3. The daily fractional reduction in detached sediment storage due to compaction (AFFIX) was decreased for corn and soybean fields.

4. Initial detached sediment storage (DETS) for pasture/other lands (segments 3, 6, 9) was increased because the value from the Four Mile Creek watershed was unusually low, representing complete pasture and meadow lands.

The final set of parameters for simulation of sediment washoff in the Iowa River Basin is contained in the HSPF input sequences available from the EPA Environmental Research Laboratory, Athens, GA.

Simulation results. Sediment washoff results for the nine segments are presented in Table 3.3. Total simulated sediment washoff for the basin during 1974-1978 was approximately 2.7 tonnes/hectare or 1.97 million tonnes. Comparative sediment washoff for the nine segments for the five year simulation period is as follows:

Simulated Sediment Washoff (tonnes/ha), 1974-1978

	soybeans	corn	pasture/other
upper watershed	5.4	5.4	0.8
middle watershed	0.8	1.1	0.06
lower watershed	5.2	5.6	0.7

TABLE 3.3 SIMULATED SEDIMENT WASHOFF FROM THE NINE SEGMENTS OF THE IOWA RIVER BASIN (1974-1978).

Sediment Washoff

Segment	1974		1975		1976		1977		1978	
	kg/ha	tonnes *1000	kg/ha	tonnes *1000	kg/ha	tonnes *1000	kg/ha	tonnes *1000	kg/ha	tonnes *1000
1	1447.4	74.7	586.5	30.2	99.9	5.2	54.2	2.8	2935.2	151.5
2	1716.1	229.3	766.9	102.5	195.5	26.1	65.9	8.8	2831.1	378.2
3	128.2	18.5	38.4	5.6	11.1	1.6	3.1	0.5	524.2	75.7
4	314.2	18.5	42.4	2.5	75.1	4.4	0.1	.007	417.2	24.6
5	397.7	47.9	76.9	9.3	135.8	16.3	0.3	.04	514.0	61.9
6	19.6	1.3	0.4	.03	2.8	0.2	0.03	.002	38.3	2.5
7	19.5	1.0	0.8	.04	0.2	.01	0.1	.005	5429.3	266.2
8	34.6	2.4	1.8	0.1	0.3	.02	0.3	.02	5338.6	378.1
9	0.3	.01	0.03	.001	0.009	.0003	0.2	.006	771.4	23.4
Total Basin	542.9	393.5	207.1	150.1	73.9	53.5	16.8	12.2	1879.5	1362.2

It should be noted that the sediment washoff totals for the nine segments are somewhat misleading. For a year with good fit between simulated and recorded runoff, such as 1974, approximately 81% of the total watershed sediment washoff emanates from the lower portion (segments 1, 2, 3); 17% of the washoff is from the middle portion (segments 4, 5, 6); and only 2% of total washoff is from the upper portion (segments 7, 8, 9). This breakdown is consistent with soils characteristics and topographical considerations. As previously noted, the upper watershed is characterized by low overland flow slopes and depressions which retard the runoff and trap eroded sediment. At the same time the Clarion and Webster soils are less likely to be detached by rainfall or transported by overland flow than are the Tama - Muscatine soils of the lower portion of the watershed. The soils of the middle and upper watershed are similar, but the hilly terrain of the middle area enhances overland flow and hence sediment transport. The lower watershed is characterized by a more gentle overland slope than the middle watershed, but the soils of the lower area are significantly more erodible than those found in the rest of the watershed. Superimposed on the more erodible soils of the lower watershed are larger quantities of rainfall, and hence more runoff. Consequently, the largest fraction of the basin's sediment washoff emanates from the lower area.

The high washoff values for the upper watershed which are reported in Table 3.3 for 1978 result from a drastic oversimulation of flow (flow at Rowan was oversimulated 190%). In 1978 simulated sediment washoff from the upper watershed area contributed 49% of the watershed total as opposed to the 2% noted in 1974. The unrealistically high values calculated for sediment washoff in 1978 bias the 5 year totals significantly; for example, 99.5% of the simulated total (1974-1978) washoff from segments 7, 8, and 9 occurred in the last year even though observed annual flows for 1974 and 1975 were both greater than 1978.

Total simulated sediment washoff for 1974-1978 accounts for 25% of the observed sediment loadings reported by the U.S. Army Corps of Engineers (Stimin, 1981) at the downstream limit of the study area near Marengo, Iowa. Thus, the simulation suggests that three-fourths of the sediment carried by the Iowa River during the 1974-1978 period resulted from channel scour; unfortunately, bed level records are not available to establish a more accurate source distribution between land surface erosion and channel scour.

Given the problems with the flow simulation and the lack of washoff or channel bed level data to refine the watershed sediment simulation, the calibration effort was restricted to three calibration runs. The results of the third run, as reported in Table 3.3 were used as input to the instream simulation of sediment transport processes in the Iowa River.

3.3 Instream Simulation of Sediment

Simulation of instream sediment transport processes (i.e., advection, deposition, scour) was performed using HSPF module section SEDTRN. The model considers inflow of sediment from upstream reaches, loadings from tributary land segments, exchange of sediments between the bed and suspension, and outflow to downstream reaches. Since both the migration characteristics and the adsorptive capacities of sediment vary significantly with particle size, the three components of sediment (sand, silt, and clay) are simulated individually, and hence initial conditions, loadings, and parameter values must be specified for each component.

Initial conditions. Prior to simulation, initial conditions must be set for suspended and settled (bed) sediment. Since suspended concentrations re-equilibrate every time step based on hydraulic conditions in the channel, initial values are not critical to simulation results as long as they are not set unrealistically high. For the Iowa River simulation, initial suspended concentrations for sand, silt, and clay were arbitrarily set at 0 mg/l, 16 mg/l, and 24 mg/l, respectively.

Data on bed depth and bed composition were not available for the Iowa River. Consequently, assumed bed depths were assigned to the 13 river reaches, and bed core sample data collected by Iowa State University at nearby Four Mile Creek were used to approximate bed composition. Initial bed depth varied from 3 feet in the upper reach to 10 feet at Marengo. The beds of the lower three reaches were characterized as 60% sand, 20% silt, and 20% clay. Bed composition in the upper ten reaches was initialized at 50% sand, 25% silt, and 25% clay.

Sediment loadings. As described in Section 3.2, module section SEDMNT was used to simulate the total sediment loading to the Iowa River from the nine land segments. Since results from SEDMNT are expressed as total sediment, it was necessary to divide the total sediment loading into sand, silt, and clay as input for the instream simulation performed by SEDTRN. Data collected by ISU for selected storms in the nearby Four Mile Creek watershed (Johnson, 1978) were used to approximate the particle size distribution for washoff from the lower third (segments 1, 2, 3) of the Iowa River Basin. Analysis of load weighted particle size distribution curves indicated only a small amount of sand in sediment loadings from storm washoff from the Tama-Muscatine soils predominant in both Four Mile Creek and the bottom third of the study basin. Between 50 and 65% of measured sediment loading is silt, and 35% to 50% is clay.

Particle size distribution for the middle (segments 4, 5, 6) and upper (segments 7, 8, 9) portions of the Iowa River Basin was based on information presented by Davidson et al., (1978). Clarion and Webster soils predominate in these areas and are

characterized by somewhat higher sand content and lower silt content. For all pasture lands, regardless of predominant soils type, it was assumed that sand particles are trapped in vegetation and do not run off. The assumed composition of sediment in runoff from soybeans, corn, and pasture is summarized below.

HSPF Segment	Land Type	Runoff Sediment Composition % Sand	% Silt	% Clay
bottom segments				
PLS 1	soybeans	5	55	40
PLS 2	corn	5	55	40
PLS 3	pasture	0	60	40
middle segments				
PLS 4	soybeans	10	50	40
PLS 5	corn	10	50	40
PLS 6	pasture	0	60	40
upper segments				
PLS 7	soybeans	10	50	40
PLS 8	corn	10	50	40
PLS 9	pasture	0	60	40

Parameters for sediment simulation. Simulation of sand transport was performed using the Toffaleti method. This method is dependent only on water temperature and the hydraulic properties of the channel, and consequently requires no additional input parameters. Simulation of silt and clay is dependent on six parameters, three of which are determined by calibration. The parameters, the basis for value selections, and final parameter values are summarized in Table 3.4.

Calibration procedures. Sediment simulation with HSPF only allows calibration of cohesive sediments (i.e., silt and clay). The three parameters used for calibration are the critical shear stress for deposition (TAUCD); critical shear stress for erosion (TAUCS); and the rate of erosion, or erodibility coefficient (M). Successful calibration of instream sediment loadings and concentrations requires a five-step procedure:

1. Using the hydraulic calibration, identify a period of record which contains events which have a good fit between recorded and simulated flows. Sediment transport processes, and the sediment calibration must be based on an accurate hydraulic representation in order for the values derived for TAUCD, TAUCS, and M to be meaningful. The calibration period must contain significant runoff events in order to properly define the runoff/sediment washoff relationship at higher flows; consequently, drought years such as 1976 and 1977 are not good periods for calibration. Based on these criteria, calendar year 1974 was selected as a calibration period for refining instream sediment parameters.

TABLE 3.4 SELECTED PARAMETER VALUES FOR INSTREAM SEDIMENT SIMULATION IN THE IOWA RIVER.

PARAMETER	DEFINITION	VALUE			BASIS FOR SELECTION
		SAND	SILT	CLAY	
D	Effective Particle diameter (mm)	.356	.0160	.00140	ASCE Sedimentation Engineering (p.20)
W	Fall velocity of particle in still water (mm/sec)	63.5	.168	.00086	Stokes Law
RHO	Density of particle relative to water	2.65	2.2	2.0	Handbook of Chemistry and Physics
TAUCD	Critical bed shear stress for deposition (kg/m2)	-	0.25	0.20	Calibration
TAUCS	Critical bed shear stress for scour (kg/m2)	-	0.73	0.59	Calibration
M	Erodibility coef-ficient (kg/m2 day)	-	15.	32.	Calibration

2. Use the HSPF DISPLAY funcion to output daily values for calculated shear stress, TAU. Identify the range of values for TAU which are characteristic of periods which exhibit significant suspension of sediment in the historical data.

3. Set values for the critical shear stress for erosion of silt and clay which bracket the period of increased suspended load. Proper selection of values for TAUCS should result in scour and suspension of noncohesive materials during periods of increased flow and shear stress, but no erosion during periods when the historical record shows minimal suspended sediment. Values of 0.73 and 0.59 kg/m2 were derived for critical shear stress for silt and clay, respectively. These values were used for all 13 reaches of the Iowa River. Given the fact that shear stress is a function of reach slope and hydraulic radius, values for TAU vary from reach to reach, and hence at any given time in the calibration, erosion may be occurring in one reach and not in others. Since the recorded sediment data are for loadings at Marengo, the selected values for TAUCS must result in the best cumulative fit at the downstream limit of the study area.

4. By examining calculated values for TAU during low flow and less turbulent portions of the simulation record, select values for TAUCD for silt and clay which allow deposition only during appropriate periods. Values of 0.25 and 0.20 kg/m2 were selected for silt and clay, respectively.

5. Adjust the erodibility coefficient, M, to obtain the best overall correspondence between observed and simulated sediment loads for events with good hydraulic fit. For the 1974 sediment calibration period values for M of 15. and 32. kg/m2-day were appropriate for silt and clay, respectively.

Calibration/simulation results. For the purpose of this demonstration project, only an approximate calibration of sediment was performed. As a first step, instream sediment transport parameters developed for nearby Four Mile Creek were applied to the Iowa River. Three additional computer runs were made to adjust these parameters until a reasonable fit to recorded data for 1974 was achieved. Necessary parameter adjustments from the Four Mile Creek values consisted of lowering the values of critical shear stress for erosion (TAUCS) for silt and clay, and lowering the erodibility coefficient (M) for clay.

The daily simulated and recorded sediment loadings and flow at Marengo are illustrated in Figure 3.4, and monthly loadings summaries for the calibration period are provided in Table 3.5.

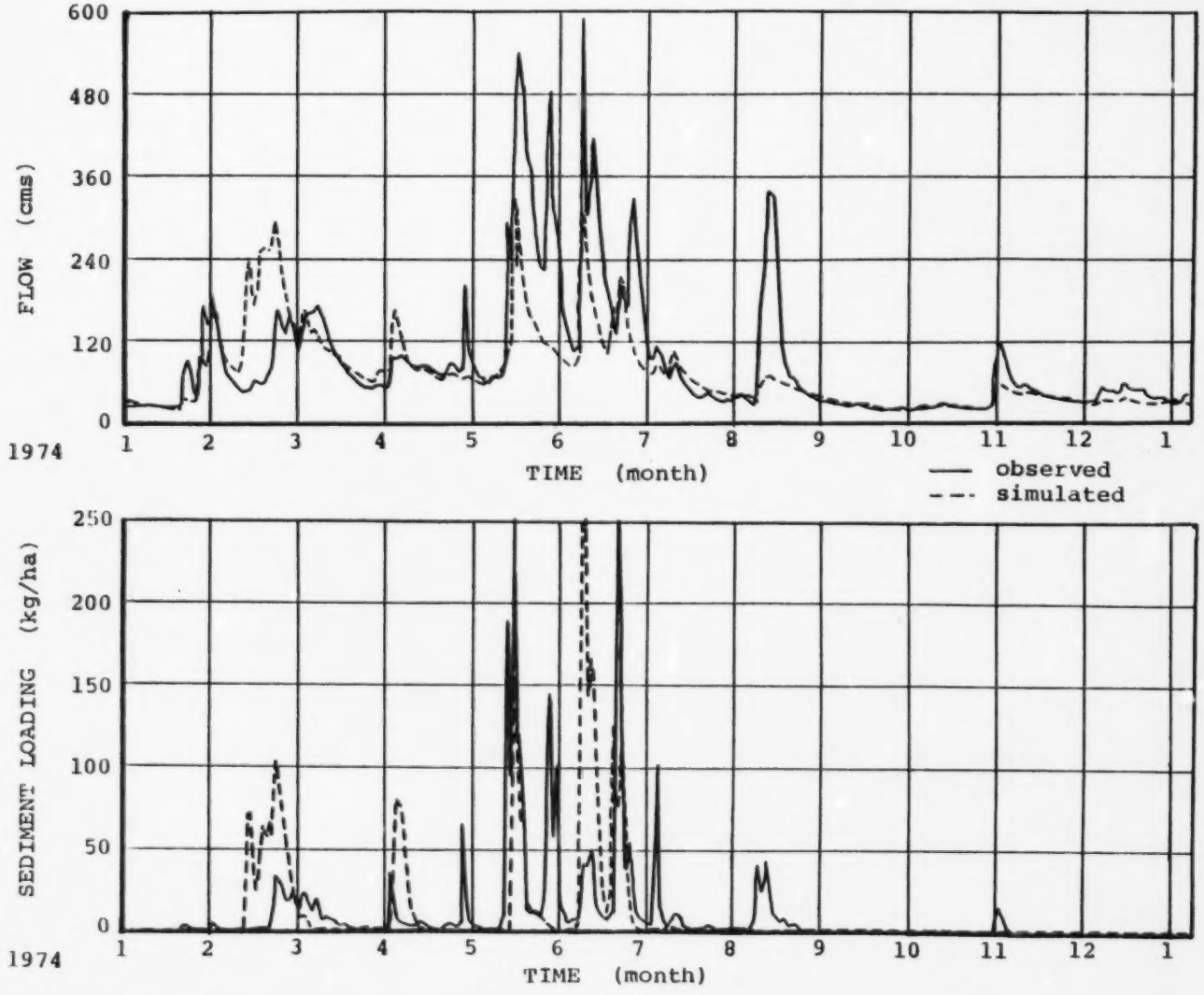

Figure 3.4 Calibration Results for Flow (top) and Sediment Loading (bottom) at Marengo, Iowa.

TABLE 3.5 MONTHLY SUMMARY OF SEDIMENT SIMULATION RESULTS AT MARENGO, IOWA, FOR CALIBRATION PERIOD (Edge-of-Stream loadings are included for comparison)

	SEDIMENT (kg/ha)		
	Recorded (at Marengo)	Simulated (at Marengo)	Simulated (edge-of-stream)
1974			
January	28	5	4
February	190	984	20
March	227	66	4
April	203	375	13
May	1432	509	140
June	1380	1952	354
July	247	11	8
August	245	2	1
September	7	0	0
October	6	0	1
November	69	1	0
December	13	0	0
TOTAL	4047	3905	545

In general, the calibration results for total sediment were fair to good. Total simulated sediment loadings for 1974 were 3905 kg/ha or approximately 2.8 million tonnes. Of this total, slightly less than 0.4 million tonnes (14%) resulted from surface washoff, while the remaining loadings were the result of channel scour. During the calibration period, simulated scour resulted in a net decrease of bed depth of 0.36 meters at Marengo. Approximately 1% of simulated total sediment load at Marengo was sand, while silt and clay contributed 14% and 85%, respectively.

After values for the sediment calibration parameters were finalized, the period from January 1974 to the end of December 1978 was simulated. Simulated and recorded sediment loadings at Marengo are compared on a yearly basis below.

Sediment loading at Marengo (kg/ha)

year	Recorded	Simulated
1974	4047	3905
1975	1501	875
1976	1233	559
1977	332	19
1978	1802 *	5690

* does not include January-March loading (data not available)

During the five-year simulation period slightly more than 25% of the total sediment loading resulted from surface washoff, with the remainder being channel scour. A net decrease of 0.72 m in bed depth was simulated at Marengo from 1974 to 1978. The sediment loadings consisted of approximately 1% sand, 30% silt, and 69% clay.

The results of the sediment calibration were encouraging, considering that only three calibration runs were performed. The model was adjusted to the point where most periods of recorded high sediment loading were simulated accordingly; simulated peaks generally corresponded to recorded peaks with an accuracy of the same order of magnitude or better. However, due to problems with (1) insufficient data, (2) discrepancies between recorded and simulated streamflow, and (3) the low level of the calibration effort, there are significant differences between simulated and observed sediment loadings. Possible reasons for these discrepancies are outlined below:

1. A major question concerns the source of sediment loadings to the Iowa River. In order to perform a meaningful instream sediment calibration, the loadings to the stream from surface washoff and erosion must be reasonably accurate. In essence, the instream calibration is merely an adjustment of bed

sediment, by deposition or scour, to make up the difference between edge-of-stream loadings and observed loadings at a point downstream. The simulated sediment erosion from the Iowa River Basin accounts for 25% of the observed loadings at Marengo. Hence, the calibration effort consisted of adjusting parameters in an attempt to generate the other 75% of observed sediment loading from channel scour. Simulated scour resulted in a decrease in bed depth of over 0.5 m in 11 of the 13 reaches. This scour still did not provide adequate loadings at Marengo in 4 of the 5 simulation years. Given that a major portion of the simulation period was characterized by low-flow, drought conditions, bed degradation of this extent is questionable. This suggests that edge-of-stream sediment loadings are perhaps higher than were simulated in this study. Unfortunately, data on edge-of-stream loadings are not available anywhere in the study area.

One possible cause for the low simulated sediment loadings is the use of a 2-hour simulation time step. Although the 2-hour time step produced only a 5-10% reduction in surface runoff compared to the 1-hour time step (Section 3.1), the associated decrease in sediment washoff would likely be greater. Moreover, the sediment erosion algorithms in HSPF or predecessor models have not been tested for sensitivity of the time step. Further study of this is warranted.

2. As mentioned previously, sediment transport processes are strongly linked to hydraulic processes, and a good hydraulic calibration is a necessity for a good sediment simulation. Due to the lack of representaive rainfall records for the watershed during 1978, simulated flow for that year was very different from observed flow. Thus, the sediment simulation for 1978 is not good. In response to the hydraulic simulation a number of intense scour events are simulated which do not agree with observed values.

3. In our simulation all bed clay was lost to scour by April 1978 in the bottom 11 reaches of the system. While this phenomenon may be partially attributed to the absence of any type of armoring factor in the SEDTRN algorithms, it is nonetheless unrealistic to simulate a bed composition void of one or more of its fractional components. Either the initial bed composition or depth should be changed to allow for more clay, or the parameters affecting scour of clay should be reduced (TAUCS and/or M).

4. Although scour/deposition phenomena are site-specific, one set of instream sediment parameters was used for the entire 300 kilometers of river channel. Parameter values were selected to produce a reasonable agreement between simulated and selected observed sediment loadings at the downstream terminus of the system. Presently it is not possible to estimate sediment transport parameters from channel geometry, sediment characteristics, or other measured data. Only if additional observed sediment data were available at upstream points would it be possible to further refine sediment parameters for specific channel reaches to simulate local variability in the scour/deposition processes.

Although the sediment simulation of the Iowa River Basin demonstrated some obvious problems and deficiencies noted above, the overall results are quite acceptable for the purposes of this study especially in light of the minimal calibration effort expended. Obviously, additional calibration and refinement is recommended prior to use of the model for water quality planning and decision-making for sediment related problems in the Iowa River Basin. The results show that HSPF can be used to model sediment processes on a river basin scale, and to provide a reasonable basis for subsequent modeling of chemical fate and transport.

3.4 Pesticide Simulation

To demonstrate HSPF capabilities for chemical fate and transport modeling in the Iowa River Basin, we chose to simulate the herbicide alachlor due to its extensive usage on corn and soybean croplands in the basin, and our previous experience with modeling alachlor in the Four Mile Creek watershed. However, the simulation effort was severely limited by the lack of any recorded alachlor concentration data on the Iowa River. For this reason, the simulation effort relied extensively upon the previous calibration and verification of alachlor on Four Mile Creek. (Donigian et al., 1983b).

The simulation of alachlor with HSPF considers the following physical and chemical processes:

1. Application of alachlor to corn and soybean cropland segments as modeled by the PERLND module of HSPF.

2. Distribution of alachlor between solution and adsorbed states, and its degradation on the land surface and subsurface.

3. Movement of alachlor over the land surface, in the soil profile, and subsequent runoff to streams.

4. Distribution of instream alachlor between dissolved and adsorbed states, and degradation of alachlor using the the RCHRES module of HSPF.

5. Scour/deposition of instream adsorbed alachlor as part of the overall chemical transport simulation.

Application rates and timing were discussed previously (Section 2.5) and were partially extrapolated from similar information developed for the Four Mile Creek study. Adjustments included differences in application rates statewide versus those in the Four Mile Creek area, and timing changes for herbicide applications occurring later in northern areas of the basin than in the southern portions.

The land surface and instream pesticide parameters used for alachlor are shown in Tables 3.6 and 3.7, respectively. These parameter sets were taken directly from the Four Mile Creek HSPF application and used unchanged for the Iowa River Basin. In the Four Mile Creek study, land surface alachlor parameters were calibrated on two small field sites within the watershed and then further adjusted in the subsequent calibration for the entire watershed. Instream parameter calibration on Four Mile Creek concentrated primarily on evaluating partition coefficients for the sand, silt, and clay fractions, and transfer rates for reaching or approaching equilibrium in addition to the decay rates. In view of the similar agricultural practices and soil conditions in Four Mile Creek and the Iowa River Basin, the parameter extrapolation was justifiable in light of the objectives of this study.

Land surface alachlor simulation. Since the alachlor parameters determined in the Four Mile Creek study were used directly in this effort, the land surface simulation results are essentially identical and will not be repeated in this report. The general behavior of alachlor in the field is characteristic of most non-persistent herbicides. With a half-life in soil of 6 to 15 days (from the decay rates in Table 3.6), alachlor decays so rapidly that less than 10% of the application amount remains in the soil two months after application and it is completely depleted within three months. Thus, with a 2.8 kg/ha application in mid-May, alachlor in the soil decreases to less than 1.0 kg/ha by mid-June and less than 0.25 kg/ha by mid-July. Consequently, during the 5-year simulation period alachlor runoff to the stream and subsequent instream concentrations occurred only during the months of May, June, and July. For additional details on the land surface simulation of alachlor, the reader is referred to the Four Mile Creek report (Donigian et al., 1983b).

Instream alachlor simulation. Typical simulated solution and sediment alachlor concentrations in the Iowa River at Marengo, and Marshalltown Iowa are shown in Figure 3.5 for 1974; loadings for the entire simulation period are shown in Table 3.8. As

TABLE 3.6 PESTICIDE AND SOLUTE LEACHING PARAMETERS FOR LAND SURFACE SIMULATION OF ALACHLOR IN THE IOWA RIVER BASIN

PARAMETER	VALUE
Decay Rates (/day)	
Surface Zone *	0.12/0.06
Upper Zone	0.045
Adsorption Parameters	
CMAX (ppm)	242
XFIX (ppm)	0.0
K1	
Surface Zone	4.0
Upper Zone	4.0
N1	1.4
Solute Leaching Parameters	
Surface Zone (SLMPF)	0.7
Upper Zone (ULPF)	5.0

* Initial decay rates were reduced to the second value ten days after application

TABLE 3.7 VALUES OF SELECTED PARAMETERS FOR INSTREAM SIMULATION OF ALACHLOR IN THE IOWA RIVER

Alachlor Decay Parameters	Rate at 20 C (/day)	Temperature Correction Coeff.
Solution	0.08	1.07
Suspended Sediment	0.10	1.07
Bed Sediment	0.12	1.07

Partition Coefficients (ml/gm)	Sand	Silt	Clay
Suspended Sediment	2.	10.	50.
Bed Sediment	10.	5.	100.

Adsorption/Desorption Rate Parameters (/day)			
Suspended Sediment	8.0	8.0	8.0
Bed Sediment	0.03	0.03	0.03

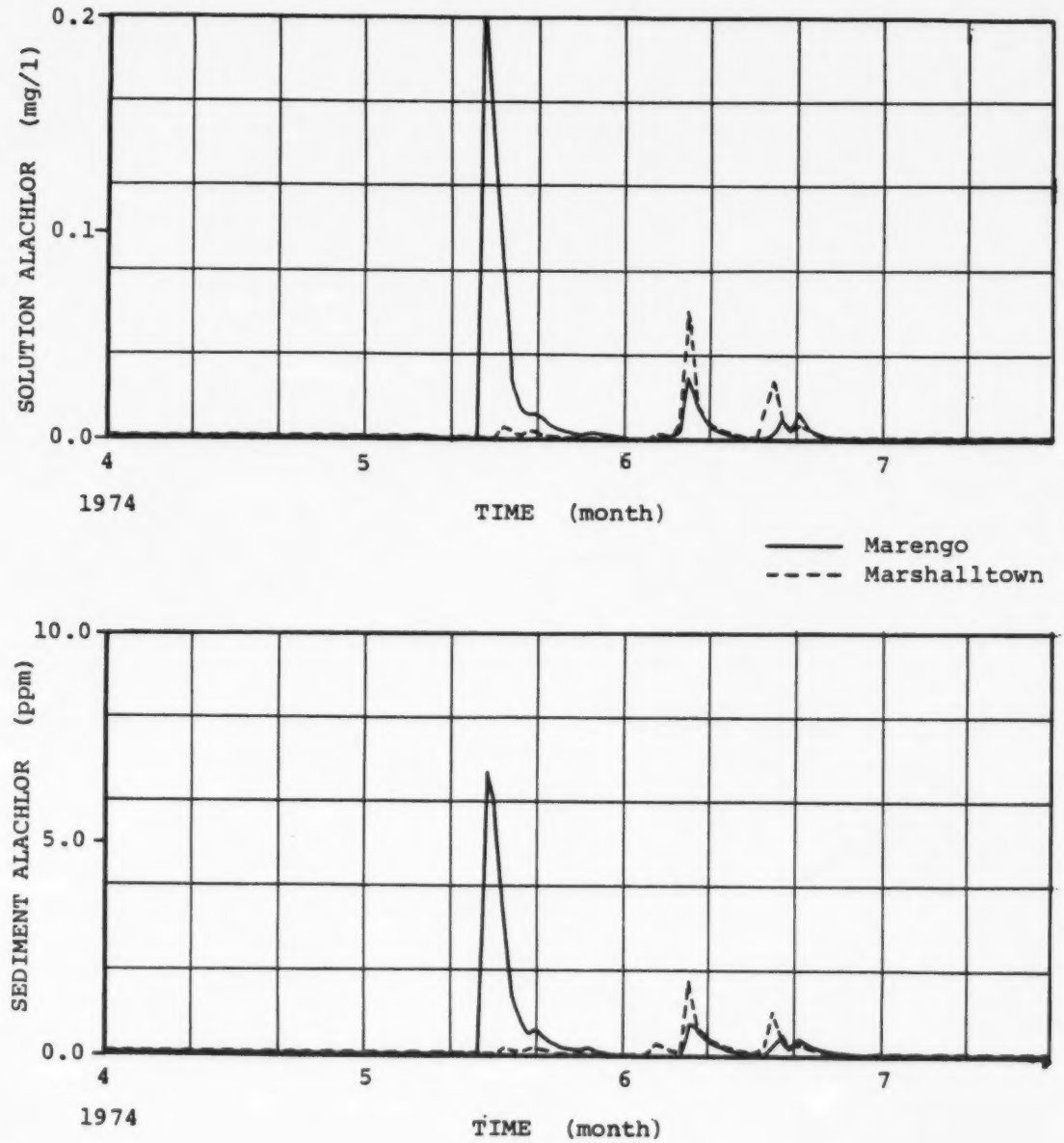

Figure 3.5 Simulated Solution (top) and Sediment (bottom) Alachlor Concentrations in the Iowa River at Marshalltown and Marengo, Iowa (1974).

TABLE 3.8 COMPARISON OF SIMULATED EDGE-OF-STREAM AND INSTREAM ALACHLOR LOADINGS AT MARENGO, IOWA (Observed data at Four Mile Creek, Iowa, are included for comparison)

ALACHLOR LOADING (kg/ha)

	Marengo		Edge-of-Stream Loadings		Four Mile Creek (Recorded)	
	Sol.	Sed.	Sol.	Sed.	Sol.	Sed.
1974	.0249	.0029	.0424	.0004		
1975	.0023	.0002	.0051	0.		
1976	.0007	0.	.0020	0.	.0007	.00005
1977	0.	0.	.0004	0.	0.	0.
1978	.0061	.0006	.0119	.0002	.0009	0.
TOTAL	0.034	0.0037	0.0618	.0006		

these results indicate, the alachlor loadings for the years 1975-1977 were significantly lower than other years due to the drought conditions which existed during that period.

In general, the simulation demonstrates high solution alachlor concentrations (10-100 ppb) in the river resulting from individual storm events occurring soon after the chemical application periods. Similar behavior and concentrations were observed in the Four Mile Creek study. Comparing the total alachlor stream loading with the total loadings at Marengo shows the amount of alachlor lost by instream decay and transport (deposition) processes. Excluding 1977, 35% to 65% of the alachlor loading to the stream decays instream, during travel time through the channel system and in the channel bed with deposited sediment, prior to reaching Marengo, IA. In Four Mile Creek, stream loadings of alachlor were reduced by only 30% before reaching the watershed outlet. Thus, as expected, instream processes play a more dominant role on water quality in large river basins than in small watersheds like Four Mile Creek.

Comparing the simulated alachlor concentrations and loadings at Marshalltown and Marengo shows the effects of the relatively hilly terrain in the southern basin area; shorter overland flow paths and greater surface runoff generally result in a larger proportion of the applied alachlor reaching the stream before it has a chance to decay on the land. This trend is reversed in 1978, however, by several high intensity rainfall events in the northern portion of the basin during the summer growing season when alachlor is applied.

As mentioned previously, no recorded pesticide data for the Iowa River above Marengo was available. However, alachlor concentrations recorded on the Iowa River (Schnoor et al, 1979) at Iowa City, downstream of Coralville Reservoir during 1975 and 1976 show maxima of 1.0 and 1.7 ppb; while our simulated peak concentrations for these years at Marengo (upstream of Coralville Reservoir) are 27. and 17. ppb, respectively. This reduction compares well with 1978 influent and effluent maximum alachlor concentrations of 10. and 0.25 ppb recorded for Lake Rathbun, a large reservoir on the Chariton River in south central Iowa (Schnoor et al, 1982). With hydraulic detention times for Lake Rathbun and Coralville Reservoir in the range of 150 days, an order of magnitude reduction between inflow and outflow concentrations is quite reasonable, indicating consistency between our simulation results and data from these reservoirs.

Comparison of the simulated alachlor loads and concentrations for the Iowa River Basin with observed data from the Four Mile Creek studies also indicate that the Iowa River simulation results are reasonable. This was expected since land use, agricultural practices, soils, terrain, and meteorological conditions over much of the Iowa River Basin are very similar to those found in Four Mile Creek.

In summary, the instream pesticide simulation results indicate that pesticide parameter values calibrated on small watersheds at least provide reasonable representations of analogous processes in large river basins. However, full verification of this conclusion must await further studies where sufficient pesticide concentration data is available for large river basins to compare with simulated values.

3.5 Nutrient Simulation

The nutrient simulation followed the same general procedure as the pesticide simulation discussed above. Nutrient parameters were adopted from the Four Mile Creek simulation and used in conjunction with the watershed hydrology and stream hydraulics to model nutrient concentrations and loadings on the Iowa River Basin for the years 1974-1978. Land surface simulation results, edge-of-stream loadings, and the resulting nutrient concentrations and loads for the Iowa River are presented, discussed, and compared with the limited observed data available. In general, this simulation serves to indicate the ability of the model to represent nutrient soil processes, nutrient loads, and the resulting nutrient concentrations at the large river basin level. The following processes were modeled in this simulation:

1. Application of fertilizer and plant residue in chemical form to the land surface or incorporated into the soil; the complete soil nitrogen cycle as represented in HSPF was modeled in the soil process simulation.

2. Mineralization, nitrification/denitrification, plant uptake, and adsorption/desorption were simulated in the soil zones; first order reaction rates were assumed and plant uptake of nitrogen was varied on a monthly basis to approximate plant growth.

3. In HSPF, nutrient movement with water and sediment occurs laterally in the surface zone and vertically with water through the soil zones; nutrients flow to the stream laterally from the surface and upper zones and with groundwater outflow.

4. Simulated nitrate and soluble ammonia loadings were input to the channel system. Nitrification and volatilization of instream ammonia were simulated along with instream transport.

In addition, dissolved oxygen was simulated since the nitrification algorithms in HSPF require a minimum dissolved oxygen content in the stream in order for nitrification to occur; however, the absence of BOD and related process simulation precluded consideration of the D.O. results.

As mentioned above, land surface nutrient parameters (shown in Table 3.9) were adopted from the Four Mile Creek calibration and used for the Iowa River Basin with only minor adjustments to the plant uptake and selected transformation rates. These soil nutrient parameters were calibrated on small field sites in the Four Mile Creek area and later extrapolated to the Four Mile Creek watershed with subsequent adjustment of subsurface nutrient transformation rates based on observed stream concentrations and loadings.

Chemical application rates, timing and methods for the nutrient simulation were developed and discussed in Section 2.5. While agricultural nutrients were simulated on all land segments, only corn receives fertilizer application since greater than 98% of the total amount of fertilizer nitrogen used in the basin is applied to that crop. In addition, a total annual fertilizer application rate of 140 kg/ha was adopted and incorporated into the soil in three applications: 20% in the fall, 50% in the spring, and 30% in summer. As discussed for pesticides, the problems of timing between a fertilizer application and subsequent runoff events also affects the nutrient simulation results. However, since nutrients are native to the soil profile, and do not exhibit rapidly decaying behavior like some pesticides, the relative timing between fertilizer application and the first runoff events is important but less critical for the nutrient simulation and resulting loadings.

In addition to fertilizer applications, nitrogen contributions from plant roots, stubble, and residue was approximated by resetting the organic nitrogen storages in the soil to their initial values at the end of each growing season. In this way, organic nitrogen would not be depleted over the simulation period, i.e. mineralization was assumed to be offset by plant nitrogen contributions to the soil.

The land surface nutrient simulation results are presented in Table 3.10 in the form of annual values for the period of January 1974 through December 1978 and the average annual value. Included in the results are the mineralization, denitrification, and plant uptake amounts resulting from the soil nutrient simulation, and the ammonia and nitrate runoff including components (surface, interflow, groundwater) from the individual land uses. These results are preliminary due to the lack of calibration; however, several points can be made. Plant uptake amounts for the various land uses are low compared to actual measured values for small sites in Four Mile Creek. For example, the nitrogen uptake by corn measured by Iowa State University on a small site in Four Mile Creek in 1978 was 189 kg/ha while our simulated values range from 139 to 186 kg/ha for the five years beginning in 1974.

For soybeans, the total nitrogen uptake should be in the range of 220-250 kg/ha which includes 20-30% derived from the soil with

TABLE 3.9 LAND SURFACE NUTRIENT PARAMETERS FOR THE IOWA RIVER BASIN

	Soybeans	Corn	Other/Pasture
FIRST ORDER RATES (/day)			
Mineralization			
Surface	0.1	0.1	0.05
Upper	0.0003	0.0003	0.00013
Lower	0.0003	0.00025	0.00015
Groundwater	0.0	0.0	0.0
Denitrification			
Surface	0.0	0.0	0.0
Upper	0.004	0.004	0.004
Lower	0.004	0.004	0.004
Groundwater	0.03	0.03	0.03
Nitrification			
Surface	3.0	3.0	2.0
Upper	0.55	0.55	0.24
Lower	0.45	0.45	0.45
Groundwater	0.2	0.2	0.2

Plant Uptake	Surf.	Upper	Lower	Surf.	Upper	Lower	Surf.	Upper	Lower
January	0.	0.	0.	0.	0.	0.	0.	0.	0.
February	0.	0.	0.	0.	0.	0.	0.	0.	0.
March	0.	0.	0.	0.	0.	0.	0.	0.	0.
April	0.	0.	0.	0.	0.	0.	0.05	0.02	0.02
May	0.	0.	0.	0.	0.	0.	0.15	0.04	0.05
June	0.05	0.03	0.	0.05	0.03	0.	0.25	0.06	0.10
July	0.10	0.12	0.05	0.25	0.25	0.05	0.25	0.07	0.15
August	0.15	0.15	0.08	0.30	0.40	0.15	0.25	0.07	0.15
September	0.15	0.20	0.10	0.30	0.40	0.15	0.20	0.07	0.15
October	0.15	0.20	0.10	0.15	0.25	0.15	0.20	0.05	0.15
November	0.	0.	0.	0.	0.	0.	0.15	0.03	0.10
December	0.	0.	0.	0.	0.	0.	0.05	0.02	0.05

ADSORPTION PARAMETERS			
CMAX (ppm)	500.	500.	500.
XFIX (ppm)	0.	0.	0.
K1			
Surface	1.	1.	1.
Upper	0.7	0.7	1.5
Lower	0.7	0.7	1.5
N1			
Surface	2.	2.	2.
Upper	1.67	1.67	1.67
Lower	1.67	1.67	1.67
SOLUTE LEACHING PARAMETERS			
Surface SLMPF	0.7	0.7	0.5
Upper ULPF	5.	5.	5.
Lower LLPF	1.5	1.5	1.5

TABLE 3.10 LAND SURFACE NUTRIENT SIMULATION RESULTS FOR THE IOWA RIVER BASIN

		Soybeans	Corn	Other/Pasture
Mineralization (kg/ha)				
1974		51.3	47.1	38.7
1975		56.0	51.0	38.3
1976		56.3	51.0	37.6
1977		56.4	51.1	38.3
1978		56.3	51.9	38.5
Average		55.3	50.4	38.3
Denitrification (kg/ha)				
1974		8.2	17.3	2.5
1975		4.9	14.2	2.3
1976		5.3	13.7	2.2
1977		6.1	13.6	2.8
1978		5.8	14.3	3.1
Average		6.1	14.6	2.6
Plant Uptake (kg/ha)				
1974		48.1	148.0	25.9
1975		34.4	139.0	25.5
1976		37.7	148.0	25.8
1977		55.0	186.0	35.7
1978		39.7	141.0	32.1
Average		43.0	152.0	29.0
Nitrate Runoff				
1974	S	0.0356	0.120	0.0213
	I	2.60	16.2	1.31
	G	20.7	35.5	5.83
	T	23.3	51.8	7.16
1975	S	0.0079	0.213	0.0038
	I	0.704	7.95	0.498
	G	8.47	17.1	3.60
	T	9.18	25.3	4.10
1976	S	0.0032	0.0337	0.0023
	I	0.608	3.99	0.451
	G	6.08	11.2	2.46
	T	6.69	15.2	2.92
1977	S	0.0015	0.0090	0.0015
	I	0.455	2.84	0.635
	G	3.66	4.06	1.90
	T	4.12	6.91	2.53

TABLE 3.10 CONTINUED

		Soybeans	Corn	Other/Pasture
Nitrate Runoff				
1978	S	0.0165	0.589	0.0109
	I	1.32	7.49	1.35
	G	10.2	9.85	5.80
	T	11.6	17.9	7.16
Average	S	0.0129	0.193	0.0080
	I	1.14	7.69	0.849
	G	9.82	15.5	3.92
	T	11.0	23.4	4.77
Ammonia Runoff				
1974	S	0.163	0.765	0.107
	I	0.491	2.24	0.512
	G	0.0641	0.0669	0.152
	T *	0.719	3.12	0.772
1975	S	0.0478	0.104	0.0177
	I	0.322	2.79	0.384
	G	0.0493	0.0548	0.114
	T	0.420	2.95	0.516
1976	S	0.0397	0.116	0.0205
	I	0.561	2.29	0.426
	G	0.0331	0.0397	0.0743
	T	0.634	2.45	0.521
1977	S	0.0192	0.0396	0.0128
	I	0.173	1.22	0.208
	G	0.0238	0.0302	0.0611
	T	0.217	1.29	0.282
1978	S	0.161	0.458	0.106
	I	0.562	4.71	0.702
	G	0.0799	0.0972	0.167
	T	0.807	5.28	0.976
Average	S	0.0861	0.297	0.0528
	I	0.422	2.65	0.446
	G	0.0500	0.0578	0.114
	T	0.559	3.02	0.613

* Total also includes adsorbed ammonia runoff (generally < 0.5%)
S - Surface outflow
I - Interflow outflow
G - Groundwater outflow
T - Total outflow

the balance coming from fixation of nitrogen gas in the air; thus the average simulated value of 43 kg/ha is somewhat low. In future calibration efforts, the nitrogen uptake rates should be adjusted upward.

Also, oversimulation of nitrate runoff during 1974 results primarily from the high initial storages which we assumed from the values measured in Four Mile Creek.

The corn land was the major contributor of nitrate loading to the stream with between 7 and 52 kg/ha (average 23 kg/ha) which compares with 39 kg/ha simulated in Four Mile Creek. Total annual loading of nitrate from all land uses averaged 14.5 kg/ha in the Iowa River Basin while 20 kg/ha was observed in Four Mile Creek. The simulation results also indicate that subsurface transport of nutrients to the stream is significant. In fact, the major portion of soluble ammonia runoff occurs through interflow.

Instream nutrient simulation. The edge-of-stream nutrient loadings calculated by module section NITR were used as input to the NUTRX module section of RCHRES and instream simulation of nutrient transport and tranformation was performed. The goal of the simulation was to calculate the nutrient loadings and concentrations at Marshalltown and Marengo which result from hydraulic mixing and instream transformation of simulated edge-of-stream loadings. This information was used as a base condition for comparison with instream nutrient concentrations and loadings simulated with the selected BMP scenario (Section 4).

Table 3.11 compares simulated edge-of-stream loadings with instream loadings at Marengo after channel mixing, volatilization, and nitrification. For the five year simulation period, nitrate loadings at Marengo are between 1% and 2% higher than edge-of-stream loadings; this increment is a result of transformation of ammonia to nitrate by instream nitrification. Ammonium/ammonia loadings at Marengo amount to 34% of edge-of-stream loadings. Simulation results indicate 53% of total NH3/NH4 was volatilized and 13% was nitrified.

Simulated nutrient concentrations at Marshalltown and Marengo for 1978 are illustrated in Figure 3.6. Limited observed data at nearby sample sites are included for comparison. Since the simulated nutrient concentrations are generally in the same range as observed values, the results are good for a model application without calibration. Figure 3.7 provides concentration frequency information for ammonia and nitrate at Marengo for mean daily concentrations during the 1974-1978 simulation period. Median concentration for ammonia was 0.04 mg/l and 90% of the values were less than 0.5 mg/l. Median nitrate concentration was 2.0 mg/l and 90% of the simulated values were less than 15 mg/l. The high nutrient concentrations represented in the low probability

TABLE 3.11 COMPARISON OF SIMULATED EDGE-OF-STREAM NUTRIENT LOADINGS WITH INSTREAM LOADINGS AT MARENGO, IOWA AFTER CHANNEL VOLATILIZATION AND NITRIFICATION

NITRATE - N (kg/ha)

	1974	1975	1976	1977	1978	TOTAL
Edge-of-Stream Loading	30.73	14.73	9.28	4.82	18.14	77.70
Increment due to Instream Nitrification	0.28	0.16	0.24	0.11	0.33	1.11
Resultant Loading at Marengo	31.01	14.89	9.52	4.93	18.47	78.81

AMMONIA/AMMONIUM - N (kg/ha)

	1974	1975	1976	1977	1978	TOTAL
Edge-of-Stream Loading	1.81	1.59	1.41	0.72	2.87	8.40
Loss due to Volatilization	1.05	0.86	0.64	0.24	1.63	4.44
Loss due to Instream Nitrification	0.28	0.16	0.24	0.11	0.33	1.11
Resultant Loading at Marengo	0.48	0.57	0.53	0.37	0.91	2.85

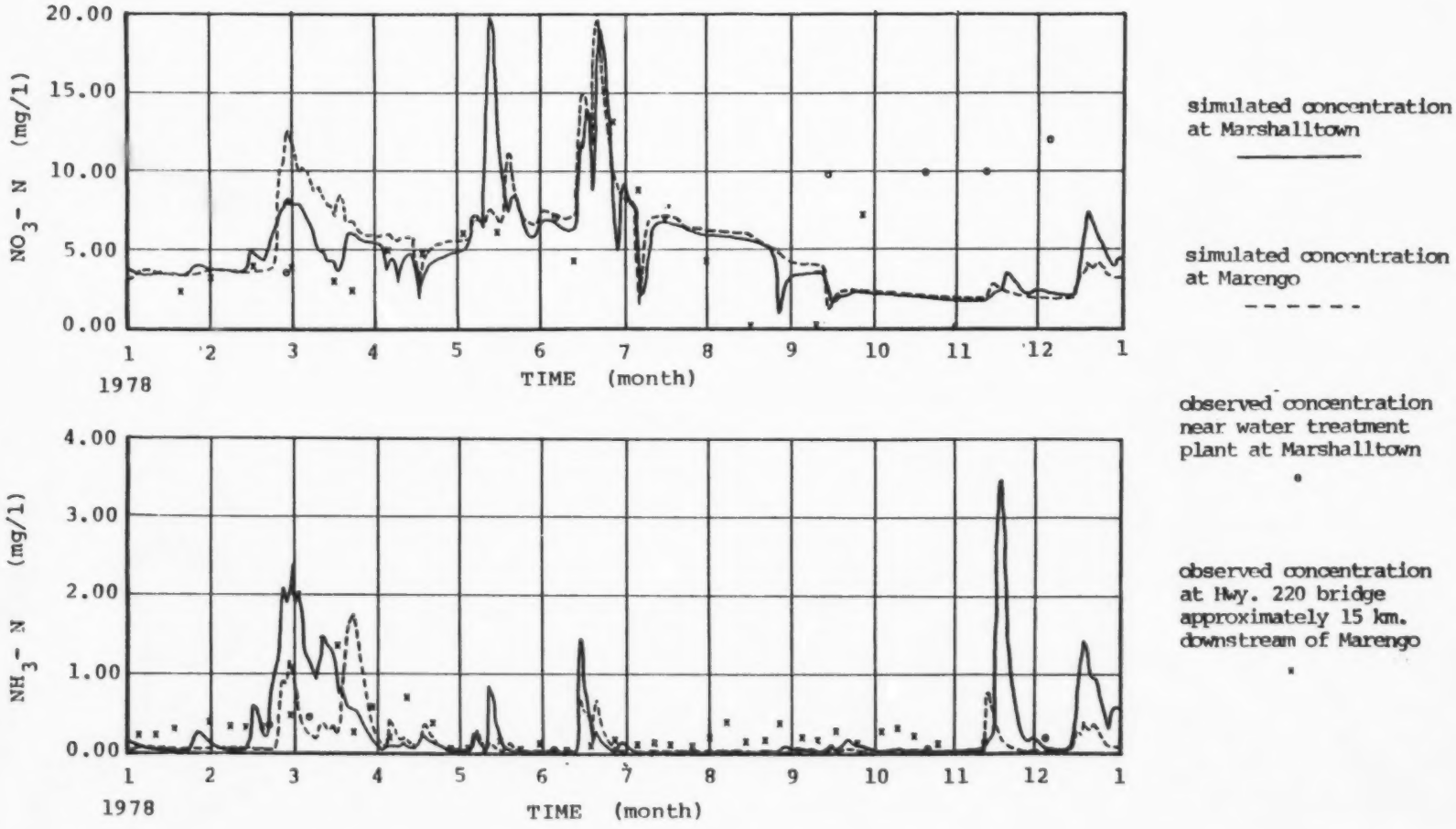

Figure 3.6 Comparison of Simulated and Observed Nutrient Concentrations near Marshalltown and Marengo, Iowa.

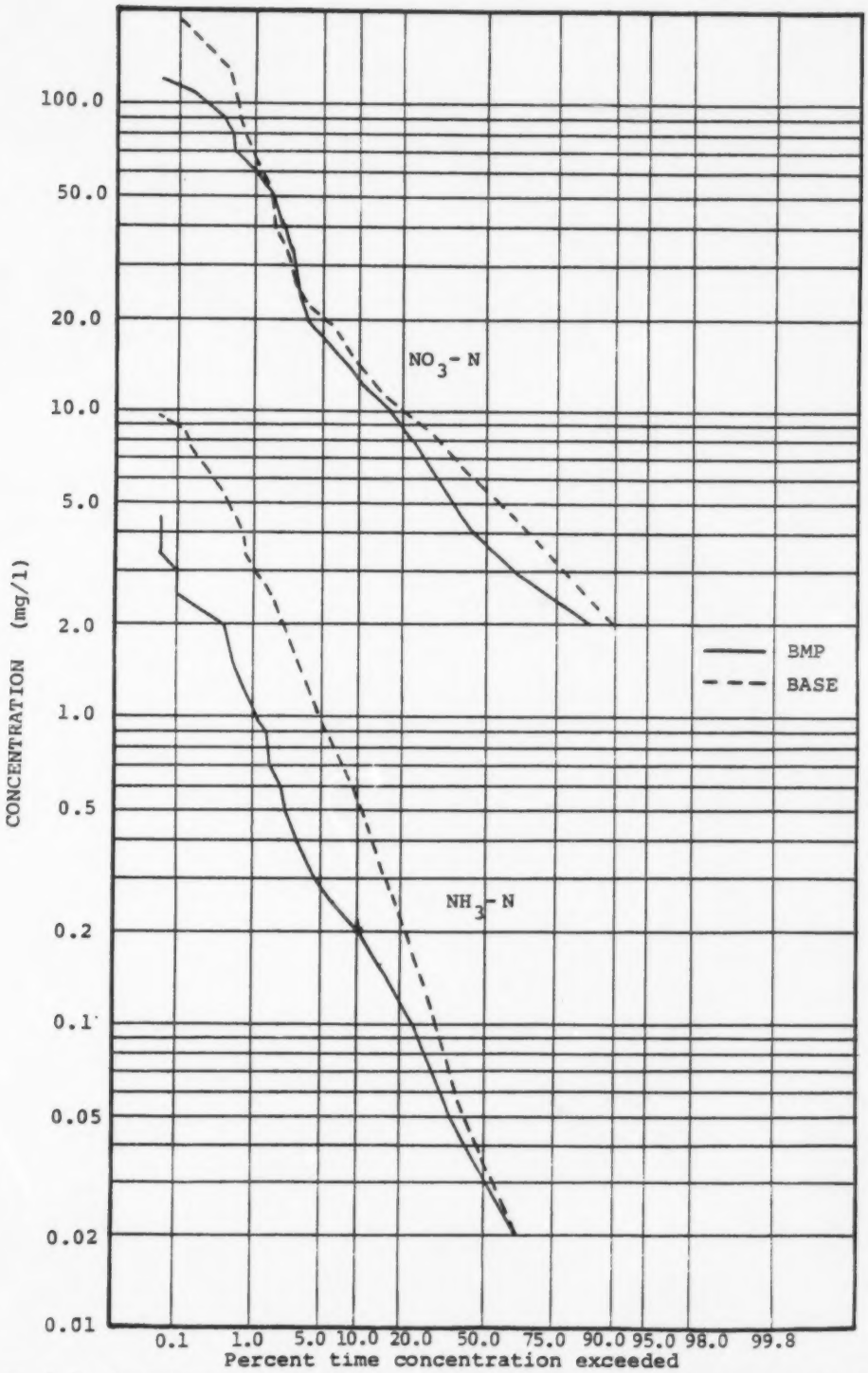

Figure 3.7 Frequency Curves for Simulated Ammonia and Nitrate at Marengo, Iowa. Base condition and nutrient BMP results are illustrated.

portion of the frequency curves result from drastic oversimulation of runoff and associated nutrient washoff during periods with non-representative rainfall records (see Section 3.1). Increased plant uptake of nitrogen and more detailed simulation of instream processes would likely reduce these extreme nitrate concentrations.

While the results of the nutrient simulation were considered adequate to establish a base condition for this demonstration project, a number of refinements would be desirable. The following issues warrant further consideration:

1. Contribution of organics and subsequent degradation to nutrients caused by runoff from animal feedlots and point source discharges was not modeled. Decay of organics can be a significant source of instream nutrients.

2. While point source contributions from municipalities and industry do not comprise a major portion of the chemical loadings to the Iowa River during normal flow conditions, their effects on overall instream water quality become more pronounced during low flow periods. Nutrient simulation during the drought years (1975-1977) could be improved by modeling major point sources.

3. Nutrient loadings from precipitation were not explicitly considered since HSPF does not currently include this capability. Enhancements to the HSPF model to allow chemical inputs with rainfall will improve nutrient simulation capabilities.

4. The relative loss of ammonia due to volatilization and nitrification, as modeled, is questionable. Too much volatilization is modeled because HSPF currently determines the amount of volatilization based on total NH3/NH4 rather than NH3 concentration. The empirical equation used in the model is intended to determine a volatilization rate based wholly on free ammonia. Hence, the user is currently faced with simulating an unrealistically large amount of volatilization, or not modeling the process at all. If a better representation of volatilization were implemented, a greater amount of nitrification would result from the higher concentrations of ambient ammonia/ammonimum.

5. Simulation of sediment-adsorbed ammonia and resulting interactions with sediment would likely reduce solution ammonia concentrations, and therefore nitrate concentrations through reduced nitrification. Such sediment-contaminant interactions for ammonia

could possibly be simulated with the GQUAL module section of HSPF which provides this capability for any chemical constituent, or through further enhancements of the RQUAL module section used for the instream nutrient modeling in this study.

As the issues listed above indicate, the nutrient simulation for this study did not consider a number of sources and reactions which are significant to most large rivers. Consequently, the results reported are limited to a reasonable representation of nutrient loadings from agricultural nonpoint sources. A more detailed consideration of nutrient sources and instream reactions is required before the results of this study could be used for planning purposes.

SECTION 4

ANALYSIS OF BMP EFFECTS ON WATER QUALITY

In order to simulate the effects of a proposed BMP scenario and to analyze the resulting impacts on water quality, the effects of the desired BMPs on model parameters must be estimated. These parameter adjustments and changes are then incorporated into the model and the simulation is performed again with the adjusted parameters; the results are then compared to base conditions in order to assess the effects of the BMP scenario that was simulated. For our demonstration we have chosen the scenario of conservation tillage plus the use of contouring; the assumptions in our simulation of this scenario are listed in Table 4.1. These changes are based on studies performed as part of the Iowa Field Evaluation Program by Donigian, et al., (1983a) to assess the effects of a variety of selected candidate BMPs on specific HSPF model parameter values.

As noted in Table 4.1, the primary components of our BMP scenario were (1) a shift from moldboard plowing to chisel plowing and field cultivation as primary tillage, (2) one summer cultivation for weed control in place of two cultivations under base conditions, and (3) allowing crop residues to remain on the field following harvest. These components were modeled by increasing parameter values for soil moisture retention (UZSN), rainfall interception, surface roughness (Manning's n), and land cover; and decreasing the sediment fines produced by tillage. The infiltration parameter was not changed, under the assumption that the primary tillage operations have similar effects on the infiltration process. Also, there was no change in chemical parameters, soil bulk density, soil temperature, or chemical application amounts, although fall fertilizer application was replaced by increasing the spring and summer applications.

Using these assumptions and associated changes in parameter values, the resulting comparison of this BMP scenario and the previously simulated base conditions is shown in Tables 4.2 and 4.3. Table 4.2 presents a detailed comparison of the edge-of-stream loadings for the BMP and base conditions while Table 4.3 lists the resulting basin-wide loadings measured at Marengo, Iowa. The other/pasture land use category shows no effects since only corn and soybean cropland is affected under this BMP scenario.

Land Surface Simulation. Over the five-year simulation period, annual runoff reductions from soybean and corn cropland were in the range of 4% to 17% with the larger reductions generally observed for corn. Groundwater outflow, the largest contributor to streamflow, shows the smallest effect (average reduction of 4.2%) from the BMP while surface runoff is decreased significantly (average reduction of 30% for soybeans and 26% for

TABLE 4.1 SELECTED BMP SCENARIO FOR SIMULATION ON THE IOWA RIVER BASIN

CONSERVATION TILLAGE PLUS CONTOURING

1. Chisel plowing replaces fall moldboard plowing on corn residue

2. Field cultivation replaces spring plowing and disking on soybean residue

3. No change in infiltration parameter

4. Residues remain after harvest, with the following reductions by tillage and decay:

Moldboard	90%
Chisel	35%
Light disk	30%
Field cultivation	30%
Winter decay	
Soybeans	30%
Corn	10%

5. Reduction in sediment fines from tillage: 50 - 70%

6. UZSN increases due to contouring and less seedbed preparation

7. One summer cultivation replaces two cultivations under base conditions

8. Rainfall interception, surface roughness (Manning's n), and land cover increase due to residues and less tillage

9. No change in chemical application amounts, but fall nitrogen fertilizer application moved to spring and summer. Incorporation distribution as follows:

	Surface	Upper
Moldboard	0%	100%
Chisel	50%	50%
Disking	20%	80%
NH3 Injection	0%	100%
Cultivation	40%	60%

10. No change in chemical (pesticide or nutrient) parameters, bulk density, or soil temperature.

TABLE 4.2 COMPARISON OF EDGE-OF-STREAM LOADINGS FOR BASE CONDITIONS and BMP SIMULATIONS IN THE IOWA RIVER BASIN

		SOYBEANS			CORN			OTHER/PASTURE
		BASE	BMP	% DIFF	BASE	BMP	% DIFF	BASE/BMP
RUNOFF (mm)								
1974	S *	32.1	22.9	-29.	41.5	31.2	-25.	14.8
	I *	50.7	44.3	-13.	58.9	52.6	-11.	48.1
	G *	204.9	201.9	-1.5	211.5	202.0	-4.5	298.2
	T *	287.8	269.1	-6.5	311.9	285.7	-8.3	361.1
1975	S	14.4	9.98	-31.	19.1	14.3	-25.	5.91
	I	23.1	20.4	-11.	28.0	24.6	-12.	22.5
	G	170.6	168.3	-1.4	174.5	165.8	-5.0	223.5
	T	208.1	198.7	-4.5	221.7	204.7	-7.6	252.0
1976	S	8.35	5.07	-39.	12.5	7.20	-42.	3.36
	I	13.6	9.96	-27.	17.6	12.3	-30.	13.5
	G	102.5	98.3	-4.1	103.7	94.7	-8.7	139.8
	T	124.5	113.4	-8.9	133.8	114.2	-15.	156.7
1977	S	3.95	2.74	-30.	4.89	3.17	-35.	1.61
	I	7.15	5.83	-18.	8.62	6.55	-24.	7.20
	G	70.1	65.2	-6.9	74.4	63.2	-15.	112.2
	T	81.2	73.8	-9.1	87.9	72.9	-17.	121.0
1978	S	50.0	36.1	-28.	56.5	43.7	-23.	27.9
	I	50.3	43.0	-14.	56.4	50.0	-11.	48.0
	G	231.0	233.9	+1.2	229.9	226.4	-1.5	294.8
	T	331.4	313.1	-5.5	342.8	320.1	-6.6	370.7
Average	S	21.8	15.3	-30.	26.9	19.9	-26.	10.7
	I	29.0	24.7	-15.	33.9	29.2	-14.	27.9
	G	156.0	154.0	-1.3	159.0	150.0	-5.7	214.0
	T	207.0	194.0	-6.3	220.0	200.0	-10.	252.0
SEDIMENT (tonnes/ha)								
1974		0.616	0.340	-45.	0.899	0.600	-33.	0.082
1975		0.224	0.097	-57.	0.375	0.197	-47.	0.023
1976		0.062	0.019	-69.	0.135	0.036	-73.	0.007
1977		0.018	0.009	-47.	0.028	0.015	-48.	0.002
1978		2.946	1.381	-53.	2.665	1.322	-50.	0.423
Average		0.773	0.369	-52.	0.820	0.434	-47.	0.107
ALACHLOR (kg/ha)								
1974		0.0905	0.0630	-30.	0.185	0.150	-19.	0.0
1975		0.0518	0.0302	-42.	0.0103	0.0081	-21.	0.0
1976		0.0102	0.0066	-35.	0.00697	0.00539	-23.	0.0
1977		0.00196	0.00188	-4.5	0.00132	0.00125	-5.6	0.0
1978		0.0764	0.0524	-31.	0.0380	0.0305	-20.	0.0
Average		0.0462	0.0308	-33.	0.0483	0.0390	-19.	0.0

TABLE 4.2 CONTINUED

		SOYBEANS			CORN			OTHER/PASTURE
		BASE	BMP	% DIFF	BASE	BMP	% DIFF	BASE/BMP
NITRATE (kg/ha)								
1974	S	0.0356	0.0250	-30.	0.120	0.0728	-39.	0.0213
	I	2.60	2.36	-9.4	16.16	15.51	-4.1	1.31
	G	20.69	20.22	-2.3	35.52	33.80	-4.8	5.83
	T	23.32	22.60	-3.1	51.80	49.38	-4.7	7.16
1975	S	0.0079	0.0043	-46.	0.213	0.228	+7.1	0.0038
	I	0.704	0.569	-19.	7.95	4.45	-44.	0.498
	G	8.47	8.08	-4.5	17.11	8.91	-48.	3.60
	T	9.18	8.66	-5.7	25.27	13.59	-46.	4.10
1976	S	0.0032	0.0018	-43.	0.0337	0.0071	-79.	0.0023
	I	0.608	0.478	-21.	3.99	2.26	-43.	0.451
	G	6.08	5.58	-8.2	11.23	6.09	-46.	2.46
	T	6.69	6.06	-9.4	15.25	8.36	-45.	2.92
1977	S	0.0015	0.0012	-20.	0.0090	0.0042	-53.	0.0015
	I	0.455	0.370	-19.	2.84	0.770	-73.	0.635
	G	3.66	3.31	-9.5	4.06	2.40	-41.	1.90
	T	4.12	3.68	-10.	6.91	3.17	-54.	2.53
1978	S	0.0165	0.0132	-20.	0.186	0.589	+217.	0.0109
	I	1.32	1.097	-17.	12.48	7.49	-40.	1.35
	G	10.24	10.07	-1.7	16.79	9.85	-41.	5.80
	T	11.57	11.18	-3.4	29.46	17.93	-39.	7.16
Average	S	0.0129	0.0091	-29.	0.193	0.180	-6.7	0.0080
	I	1.14	0.975	-14.	7.69	6.10	-21.	0.849
	G	9.82	9.45	-3.8	15.5	12.21	-21.	3.92
	T	11.0	10.44	-5.1	23.4	18.49	-21.	4.77
AMMONIA (kg/ha)								
1974	S	0.163	0.123	-25.	0.765	0.563	-26.	0.107
	I	0.491	0.364	-26.	2.24	1.59	-29.	0.512
	G	0.0641	0.0632	-1.4	0.0669	0.0638	-4.5	0.152
	T	0.719	0.551	-23.	3.12	2.23	-28.	0.772
1975	S	0.0478	0.0291	-39.	0.104	0.707	+582.	0.0177
	I	0.322	0.218	-32.	2.79	1.14	-59.	0.384
	G	0.0493	0.0484	-1.8	0.0548	0.0479	-12.	0.114
	T	0.420	0.296	-29.	2.95	1.90	-35.	0.516
1976	S	0.0397	0.0234	-41.	0.116	0.0384	-67.	0.0205
	I	0.561	0.354	-37.	2.29	0.573	-75.	0.426
	G	0.0331	0.0312	-5.7	0.0397	0.0302	-24.	0.0743
	T	0.634	0.409	-35.	2.45	0.641	-74.	0.521

TABLE 4.2 CONTINUED

		SOYBEANS			CORN			OTHER/PASTURE
		BASE	BMP	% DIFF	BASE	BMP	% DIFF	BASE/BMP
AMMONIA (kg/ha)								
1977	S	0.0192	0.0142	-26.	0.0396	0.0256	-35.	0.0128
	I	0.173	0.105	-39.	1.22	0.192	-84.	0.208
	G	0.0238	0.0218	-8.4	0.0302	0.0211	-30.	0.0611
	T	0.217	0.141	-35.	1.29	0.238	-82.	0.282
1978	S	0.161	0.129	-20.	0.458	2.53	+451.	0.106
	I	0.562	0.376	-33.	4.71	1.67	-64.	0.702
	G	0.0799	0.0795	-0.6	0.0972	0.0766	-21.	0.167
	T	0.807	0.587	-27.	5.28	4.34	-18.	0.976
Average	S	0.0861	0.0637	-26.	0.297	0.773	+160.	0.0528
	I	0.422	0.283	-36.	2.65	1.03	-61.	0.446
	G	0.0500	0.0488	-2.4	0.0578	0.0479	-17.	0.114
	T	0.559	0.397	-29.	3.02	1.87	-38.	0.613
MINERALIZATION (kg/ha)								
1974		51.3	51.0	-0.5	47.1	46.4	-1.3	38.7
1975		56.0	55.8	-0.3	51.0	50.5	-1.1	38.3
1976		56.3	56.1	-0.3	51.0	50.5	-1.0	37.6
1977		56.4	56.3	-0.2	51.1	50.7	-0.9	38.3
1978		56.3	56.9	-0.7	51.9	51.3	-1.3	38.5
Average		55.3	55.2	-0.2	50.4	49.9	-1.0	38.3
DENITRIFICATION (kg/ha)								
1974		8.23	8.28	+0.7	17.3	18.5	+6.9	2.46
1975		4.91	4.86	-0.9	14.2	12.4	-13.	2.26
1976		5.26	5.16	-1.9	13.7	12.2	-11.	2.17
1977		6.14	5.98	-2.6	13.6	12.2	-10.	2.82
1978		5.80	5.78	-0.4	14.3	12.6	-11.	3.11
Average		6.1	6.01	-1.6	14.6	13.6	-6.8	2.6
PLANT UPTAKE (kg/ha)								
1974		48.1	49.6	+3.1	147.8	177.,6	+2.0	25.9
1975		34.4	35.8	+3.8	138.6	153.0	+10.	25.5
1976		37.7	38.4	+1.8	148.5	159.2	+7.	25.8
1977		55.0	54.4	-1.1	186.5	190.4	+2.	35.7
1978		39.7	40.7	+2.3	141.2	156.9	+11.	32.1
Average		43.0	43.8	+1.9	152.0	167.4	+10.	29.0

* S = Surface Outflow
I = Interflow Outflow
G = Groundwater Outflow
T = Total Outflow

TABLE 4.3 COMPARISON OF LOADINGS IN THE IOWA RIVER AT MARENGO FOR BASE CONDITIONS AND BMP SIMULATIONS

		BASE	BMP	% DIFFERENCE
RUNOFF (mm)	1974	183.0	170.0	-7.1
	1975	124.0	116.0	-6.4
	1976	80.0	73.9	-7.6
	1977	47.8	42.4	-11.3
	1978	299.0	280.0	-6.4
	Average	147.0	136.0	-7.5
SEDIMENT	1974	3.91	2.62	-33.0
(tonnes/ha)	1975	0.88	0.47	-47.0
	1976	0.56	0.12	-79.0
	1977	0.019	0.012	-37.0
	1978	5.69	5.49	-3.5
	Average	2.21	1.74	-21.0
SOLN. ALACHLOR	1974	0.0278	0.0219	-21.0
(kg/ha)	1975	0.0026	0.0017	-35.0
	1976	0.0008	0.0004	-50.0
	1977	0.00	0.00	-
	1978	0.0068	0.0048	-29.0
	Average	0.0076	0.0058	-24.0
SED. ALACHLOR	1974	0.0032	0.0020	-38.0
(kg/ha)	1975	0.0002	0.0001	-50.0
	1976	0.00	0.00	-
	1977	0.00	0.00	-
	1978	0.0007	0.0004	-43.0
	Average	0.0008	0.0005	-38.0
NITRATE N	1974	31.0	29.8	-3.9
(kg/ha)	1975	14.9	9.5	-36.0
	1976	9.5	6.2	-35.0
	1977	4.9	3.0	-39.0
	1978	18.5	13.1	-29.0
	Average	15.8	12.3	-22.0
AMMONIA N	1974	0.48	0.41	-15.0
(kg/ha)	1975	0.57	0.30	-47.0
	1976	0.53	0.20	-62.0
	1977	0.37	0.09	-76.0
	1978	0.91	0.46	-49.0
	Average	0.57	0.29	-49.0

corn). As a consequence, sediment losses which come entirely from the surface were also reduced dramatically with soybean and corn reductions ranging from 45% to 69% (average 52%) and 33% to 73% (average 47%), respectively. In addition, BMP effects on erosion were much more pronounced than the resulting loading at Marengo since most of the sediment loading at Marengo resulted from channel scour processes rather than from land surface erosion. Solution alachlor edge-of-stream loading reductions were in the range of 4% to 42% with slightly greater reductions occurring on soybeans than corn; the average decrease for soybeans was 33%, and 19% for corn.

Nutrient simulation for both base conditions and the BMP was also performed for the entire five-year simulation period. As shown in Table 4.2, total annual nitrate nitrogen reductions ranged from 3% to 10% for soybeans and 5% to 54% for corn. Ammonia nitrogen was reduced 23% to 35% for soybeans and 18% to 82% for corn. The nitrate reductions were lowest in the first year of the simulation period since we assumed the same initial storages in the soil for both the base conditions and the BMP. Lower nitrate and higher ammonia storages in the first year of the BMP simulation would have been more consistent with the storages calculated during the rest of the period. In fact, the initial nitrate nitrogen storage was high enough to preclude a significant reduction by the BMP scenario in 1974. The <u>increases</u> in surface runoff of nitrate and ammonia shown for the BMP simulation in 1975 and 1978 were due to inadvertent applications of fertilizer to the land immediately preceding high intensity rainfall events leading to very high surface runoff before the chemical was leached into the soil. Although the percentage increase was large, the absolute amounts were small compared to total loadings.

The effects of the BMP scenario upon surface nutrient processes occurring on the land surface are relatively small since the primary effect is to reduce surface runoff and not to affect the plant growth and other biological/chemical processes occurring in the soil. In addition, the large storage of nutrients generally present on the land precludes any significant change in the nutrient processes due to a relatively small change in runoff. Consequently, the plant uptake, denitrification, and mineralization are not significantly changed under the BMP scenario.

<u>Instream Simulation</u>. Table 4.3 shows the effects of the BMP scenario on the runoff and water quality of the Iowa River measured at Marengo, Iowa. Over the five-year simulation period, total annual runoff reductions at Marengo were in the range of 7% to 11% with an overall average of 7.5% reduction. Annual sediment loss reductions were generally higher varying from 4% to 79% reduction with an overall average of 21% reduction over the simulation period. These sediment loss reductions are somewhat

less than what might be expected; however, as discussed above, a significant portion of the total sediment loss is derived from the channel system itself which would not be significantly affected by the BMPs. Also, the 4% reduction in 1978 biased the average; the average reduction in 1974 to 1977 was 49%. Solution alachlor at Marengo was reduced from 0% to 50% with an average of 24% reduction over the simulation period; sediment alachlor was also reduced from 0% to 50%, averaging 37.5% over the period. The 0% reduction in alachlor occurred in 1976 and 1977, the years of extreme drought in central Iowa.

The instream nutrient results are also presented in Table 4.3 as annual nitrate and ammonia loadings at Marengo. The nitrate nitrogen reductions ranged from 4% to 39% over the simulation period with an average reduction of 22%. Ammonia nitrogen was reduced by 15% to 76% with an average reduction of 49%; this reduction was considerably higher than the nitrate reduction due to reduced sediment loadings that transport the adsorbed ammonia nitrogen. As discussed above for the edge-of-stream loadings, the reductions for nitrate and ammonia were lowest in the first year of the simulation period due to the same initial nutrient storages in the soil for both the base conditions and the BMP.

Figure 3.7 compares the frequency curves for nutrient concentrations at Marengo resulting from simulation of base and BMP conditions for the 1974-1978 period. Both the nitrate and ammonia curves indicate a general decrease of instream nutrient concentrations for the BMP scenario; extreme and median values are reduced for both constituents. Generally speaking, reductions in ammonia concentration resulting from the modeled BMP scenario were relatively more pronounced than reductions in nitrate, particularly for extreme values. For example, the 10% level for ammonia (i.e., the concentration which was exceeded 10% of the time) was reduced by 60% from the base conditions to the BMP scenario, while only a 13% reduction in nitrate occurred.

The best management practices are more effective in reducing peak concentrations of ammonia than nitrate because improved sediment erosion control prevents adsorbed ammonia from reaching the channel, while erosion control has a limited effect on the highly mobile nitrate species. Reductions for median concentrations resulting from the BMP scenario were 18% and 34% for ammonia and nitrate, respectively. The relatively large reduction in nitrate concentration for mid-range events can be attributed to two phenomena resulting from best management practices: (1) increased nitrate uptake by plants and (2) decreased groundwater flow. Large quantities of nitrate are carried to the river by groundwater flow, and reduction of instream nitrate concentrations is a natural consequence of decreasing groundwater flow and associated concentrations. On the other hand, ammonia loadings from groundwater are relatively small, and instream concentrations of ammonia are not nearly as sensitive to reductions in groundwater flow.

Risk Assessment. One of the possible uses of continuous modeling of chemical fate and transport is to evaluate the risk or exposure of aquatic organisms to various magnitudes and durations of chemical concentrations. Figure 4.1 demonstrates how the frequency, or percent of time, of acute, chronic, and sublethal conditions might be determined for a particular organism and stream given a time series of chemical concentrations. This methodology was developed in work by Onishi et al., (1979) in providing a procedure to assess the risk of chemical exposure to aquatic organisms. Using these procedures the simulated chemical concentrations under both base conditions and the BMP scenario were analyzed to determine the percent of time conditions within each region shown in Figure 4.1 would exist. The results of this analysis are shown in Table 4.4; the table title indicates a hypothetical organism because all the values observed for alachlor concentrations were considerably lower than any of the MATC (maximum acceptable toxicant concentration) values for common species of fish found in the Iowa River.

Table 4.4 also shows the reductions in the fraction of time when acute and lethal conditions exist under the simulated BMP scenario. The specific choice of MATC and lethality data chosen for this analysis resulted in no change in the percent of time when acute conditions existed, primarily because the maximum simulated value was still sufficiently large to exceed the values that define the acute region under both conditions (base conditions and BMP scenario).

A concentration of 30 ppb solution alachlor defined the single day (24-hour) acute concentration threshold for our hypothetical organism. The maximum observed solution alachlor concentrations in each year for both the base conditions and BMP scenario are listed below:

Annual maximum daily concentrations of solution alachlor (ppb)

Year	Date	Base	BMP	% Change
1974	5/16	286.	262.	- 8.4
1975	6/15	27.	16.	-41.
1976	5/29	17.	12.	-29.
1977	5/22	2.0	1.6	-20.
1978	5/18	105.	90.	-4.

Thus, although the BMP scenario provided substantial reductions in the peak concentrations ranging from 9% to 41%, the absolute reductions in 1974 and 1978 were not sufficient to reduce the concentrations below the 30 ppb threshold used in our risk analysis.

The fraction of time when lethal conditions exist, both acute and chronic, is represented by the values listed on the line entitled

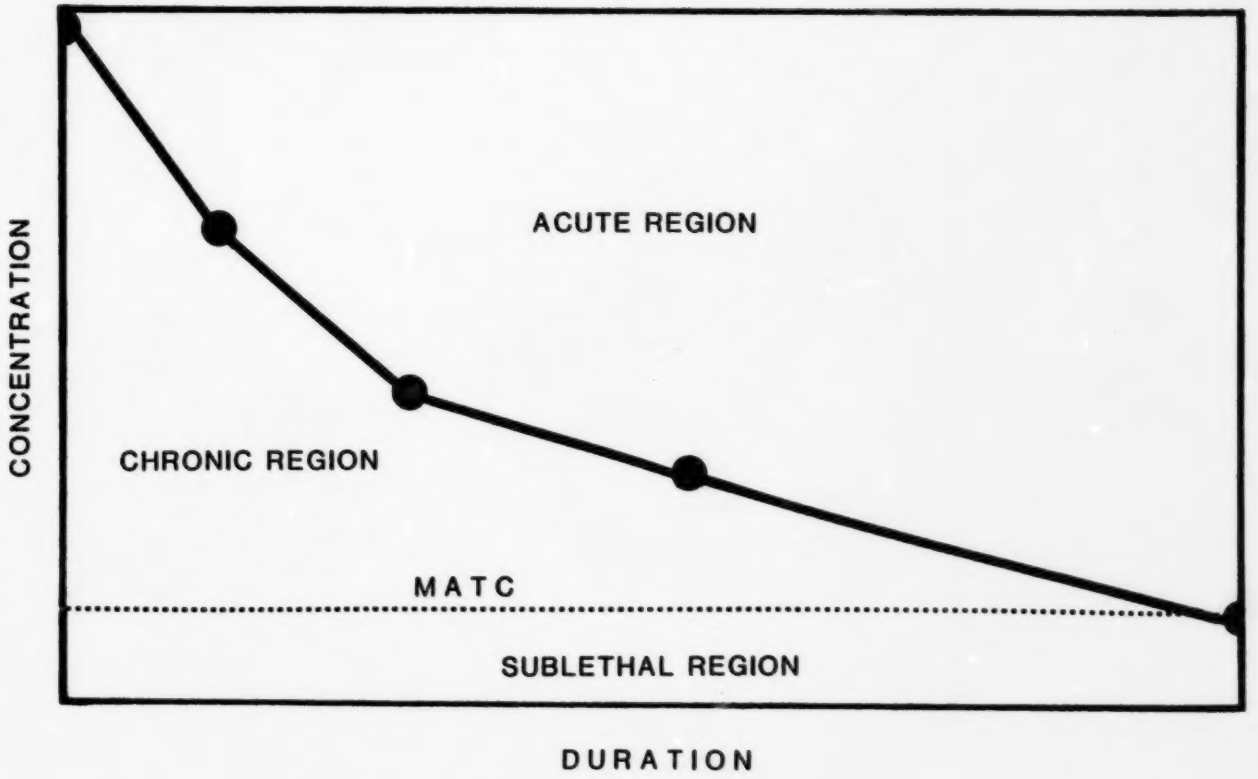

Figure 4.1 Lethality Analysis of Chemical Concentration Data

TABLE 4.4 LETHALITY ANALYIS OF BMP SCENARIO FOR ALACHLOR IN THE IOWA RIVER AT MARENGO, IOWA

	Global Exceedance (% of time)		
	Base Conditions	BMP Scenario	% Change
Acute Region	0.49	0.49	0
Above MATC Value	3.50	2.68	-23.4
Sublethal Region (below MATC)	96.50	97.32	- 0.8

MATC - Maximum Acceptable Toxicant Concentration (0.003 mg/l used above)

"Above The MATC Value" in Table 4.4. The reductions indicate a 23% reduction in the percent of time when lethal conditions occurred in the watershed. Obviously, reductions in the percent of time for lethal conditions will correspond to an increase in time for sub-lethal conditions. Although the values listed here are specific to the conditions under which this BMP scenario was simulated, the overall methodology and analysis indicates how the procedures described here can be used to evaluate the effects of BMP scenarios on the resulting risk of exposure of aquatic organisms to chemicals.

SECTION 5

STUDY CONCLUSIONS AND RECOMMENDATIONS

This demonstration application of HSPF to the Iowa River Basin has produced valuable insight and conclusions on modeling agricultural runoff and resulting water quality in large river basins. Additionally, HSPF capabilities to perform this type of modeling have been assessed, problems have been identified, and recommendations have been developed both to improve the simulation of the Iowa River with current model capabilities and to guide future model improvements.

Specific conclusions from this study are as follows:

1. HSPF can be used to model the flow, sediment, and water quality (specifically pesticides and nitrogen nutrients) from large agricultural river basins. This includes both land surface and subsurface generation of agricultural runoff (quantity and quality) and resulting instream water quality.

2. Many model parameters primarily related to hydrology and sediment, are calibration dependent, i.e., although initial values can be obtained from the literature and past experience, parameter adjustment through comparison of simulated and observed information can improve simulation results. Fortunately, extrapolation of parameter values from nearby or representative calibrated watersheds can be performed with a reasonable degree of confidence, as was done in this study.

3. Determination of representative meteorologic time series data, primarily precipitation and air temperature, for different portions of the basin is a critical component in basin-scale modeling. Lacking representative data, comparison of frequency information (e.g., simulated and observed flow frequency) is a better measure of overall simulation accuracy than comparison of individual storm event data.

4. With minimal calibration effort, simulation of flow frequencies on the main stem of the Iowa River was fair to good in this study. In spite of problems with deficient rainfall data and with modeling the volume and timing of snowmelt runoff, the flow simulation was more than adequate for the purposes of this demonstration study. Further calibration and watershed segmentation efforts would definitely improve the preliminary results presented here.

5. Sediment simulation was fair to poor due to insufficient calibration, lack of data, and model deficiencies. A major problem was related to the ability to define and then simulate the relative sediment contributions from land surface erosion and channel scour. Since the water quality constituents simulated were primarily soluble forms, the sediment simulation discrepancies were judged to be acceptable for this study.

6. Simulated alachlor loadings and concentrations in the Iowa River were in the expected range in comparison to the Four Mile Creek data, and were consistent with the limited alachlor data available on streams and reservoirs in central Iowa.

7. Simulated nitrate-nitrogen and ammonia-nitrogen concentrations between Marshalltown and Coralville Reservoir were usually within the range of observed grab sample data, but occasional over-simulation was observed during low flow conditions in the five-year simulation period. These preliminary results are promising considering the many simplifying assumptions included in this demonstration study. Further improvement of both the land surface and instream nitrogen simulation would readily improve the model results.

Specific recommendations to improve the simulation of the Iowa River Basin, using existing capabilities of HSPF, are as follows:

1. Additional hydrologic calibration with emphasis on the development of representative meteorologic time series, primarily precipitation and air temperature, using additional stations.

2. Refinement of the sediment simulation including analysis of source distribution (i.e., erosion versus channel scour), further calibration of channel parameters, and additional assessment of bed scour simulation using whatever additional data can be uncovered.

3. Verification of both hydrology and sediment simulation if possible with available data.

4. Refinement of alachlor soil adsorption and leaching parameters based on soil characteristics in different parts of the basin.

5. Calibration of nitrogen plant uptake parameters and soil transformation parameters in conjunction with a re-assessment of fertilizer application rates.

6. Analysis of the impacts of animal feedlots and point sources of pollution, especially during low-flow periods.

7. Calibration of instream water quality parameters related to alachlor-sediment adsorption, solution, alachlor decay and bed decay, nitrification, and ammonia volatilization. Simulation should be expanded to include water temperature, BOD, benthal ammonia release, and biological components. Sediment-contaminant interaction capabilities in GQUAL could be used to assess the impact of ammonia-sediment interactions on nitrate and ammonia concentrations.

8. Analysis of the effects of different simulation time intervals, greater detail in channel and land segment division, and better spatial definition of land use categories, chemical application rates, and existing agricultural practices.

The following improvements in HSPF have been identified in this study and are recommended for further consideration:

1. Accommodation of nutrient and chemical inputs with precipitation.

2. Simulation of both ionized and un-ionized forms of ammonia, and sediment-ammonia interactions.

3. Better definition of bed water quality and sediment processes, possibly with a layered representation.

4. Output of nutrient transformation amounts (e.g., nitrification, mineralization, volatilization) in both PERLND and RCHRES as aids in calibration and analysis of model results.

Our experience in applying HSPF in this study has shown that HSPF provides a viable means of representing agricultural runoff and the resulting downstream water quality conditions in large river basins. As a result of both this modeling effort and our Four Mile Creek study, we have demonstrated that HSPF is a flexible and realistic means of approximating the impacts (quantity and quality) of candidate BMPs on small watersheds and large river basins. Moreover, risk assessment procedures can be used with the chemical concentration time series produced by the model to evaluate impacts on selected aquatic organisms. However, true verification of the ability to simulate the effects of BMPs must await the availability of post BMP implementation data. Watersheds like Four Mile Creek with extensive baseline data provide an excellent opportunity for continued data collection following BMP implementation so that the real impacts can be analyzed and modeling capabilities can be evaluated and improved.

SECTION 6

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